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Coal Gasification/Gas Cleanup Test Facility Volume II. Environmental Assessment of Operation with Devolatilized Bituminous Coal and Chilled Methanol

North Carolina State Univ. at Raleigh

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COAL GASIFICATION/GAS CLEANUP TEST FACILITY: VOLUME II. ENVIRONMENTAL ASSESSMENT OF OPERATION WITH DEVOLATILIZED BITUMINOUS COAL AND CHILLED METHANOL.

by

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16. ABSTRACT The report gives results of initial runs of a pilot-scale coal gasification and gas cleaning plant at North Carolina State University. In these runs, a devolatilized Western Kentucky No. 11 bituminous coal was gasified with steam and oxygen, and chilled methanol was used as the acid-gas removal solvent. Material balances were obtained for major elements and trace elements judged to be both volatile and environmentally hazardous. Emissions of sulfur gases in the various plant effluent streams were also measured. A two-stage gasifier model provided good correlation of make-gas production with the mean gasifier temperature and the steam-to-carbon feed ratio. The sulfur-containing species produced in the gasifier included large quantities of H2S and COS, significant amounts of CS2, and trace amounts of methyl mercaptan and thiophene. As, Pb, and Hg were all volatilized and then recondensed to varying degrees as the product gas cooled. As was the least volatile of the three trace elements, and Hg was the most volatile. The acid gas removal system, with methanol as the cleaning solvent, removed at least 94% of the acid gases fed to the system. No significant accumulation of hydrocarbons in the circulating methanol was noted after nearly 60 hours of operation.

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Assessments		Environmental Assessment	14B	
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ABSTRACT

This report describes the results of an initial series of runs made using a pilot-scale coal gasification and gas cleaning facility located at North Carolina State University. The plant was described in detail in Volume I of this series (Ferrell et al., 1980a) and consists of a fluidized bed reactor, a cyclone and venturi scrubber for particulates, condensables, and solubles removal, and absorption and stripping columns for acid gas removal and solvent regeneration.

In the initial series of runs performed on this facility, a devolatilized Western Kentucky No. 11 bituminous coal was gasified with steam and oxygen, and chilled methanol was used as the acid gas removal solvent. Material balances were obtained for major elements (C,H,O,N,S) and selected trace elements judged to be both volatile and environmentally hazardous. Emissions of sulfur gases in the various plant effluent streams were also measured.

Refinements of sampling and analysis procedures since the first volume of this report was issued have enabled the consistent closure of material balances on major elements to within 5%, lending credence to the reported emission data. A two-stage gasifier model which incorporates the kinetics of the water gas shift reaction provides a good correlation of make gas production and composition with the mean gasifier temperature and the steam-to-carbon feed ratio. This result is valuable in and of itself, but it is also significant in that it allows the predetermination of conditions needed to produce a specified feed to the gas cleaning subsystems for environmental impact studies.

The sulfur-containing species produced in the gasifier included large quantities of hydrogen sulfide and carbonyl sulfide, significant amounts of carbon disulfide, and trace amounts of methyl mercaptan and thiophene. At the higher reactor temperatures, equilibrium appeared to have been achieved in the H_2S-COS shift reactions.

Arsenic, lead, and mercury are all volatilized in gasification, and recondense to varying degrees as the product gas cools. Arsenic is the least volatile of the three trace elements, and is essentially completely removed in the condensed effluents; lead is more volatile than arsenic; and mercury is by far the most volatile of the three elements, with as much as 50% remaining unrecovered by condensation.

In four integrated runs, the acid gas removal system, with methanol as the cleaning solvent, removed at least 94% of the acid gases (CO_2, H_2S, COS) fed to the system. No significant accumulation of hydrocarbons in the circulating methanol was noted after nearly 60 hours of operation. Indications are that the CO_2, H_2S, and COS in the gas and liquid streams at the top of the absorber are in equilibrium. Improved removal efficiencies would be possible if the methanol entering the absorber had been more effectively stripped. These four runs serve as a basis with which to compare subsequent runs to be made with a New Mexico coal.

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INTRODUCTION

The North Carolina State University coal gasification/gas cleaning test facility consists of a fluidized bed gasifier; a cyclone, venturi scrubber, and filters for particulates, condensables, and solubles removal (PCS removal system); and an absorption column, flash evaporator, and stripping column for acid gas removal (AGRS). The overall objective of the project is to characterize the gaseous and condensed phase emissions from the gasification-gas cleaning process, and to determine how emission rates of the various pollutants depend on adjustable process parameters. Specific tasks to be performed are:

1. Identify and measure the gross and trace species concentrations in the gasifier product streams.
2. Correlate measured emission levels with coal composition and gasifier operating variables.
3. Perform material balances around the gasifier, raw gas cleanup system, and acid gas removal system, and determine the extent to which selected species are removed from the synthesis gas in each subsystem.
4. Correlate measured extents of conversion and removal efficiencies for various species with system operating variables.
5. Evaluate and compare the performance characteristics of alternative acid gas removal processes.
6. Use results to develop models for the gasification and gas cleanup processes.

A detailed description of the pilot plant and associated facilities for sampling and analysis and data acquisition and logging is given in Volume I of this report (Ferrell et al., 1980a). Simplified schematic drawings are shown in Figures 1 and 2.

Based on the experience of the Institute of Gas Technology, the system chosen for startup and initial operation was Western Kentucky No. 11 pretreated coal char as gasifier feed with methyl alcohol as the AGRS solvent. The first 13 runs on the facility were used primarily for the

FIGURE 1

Gasifier-PCS System

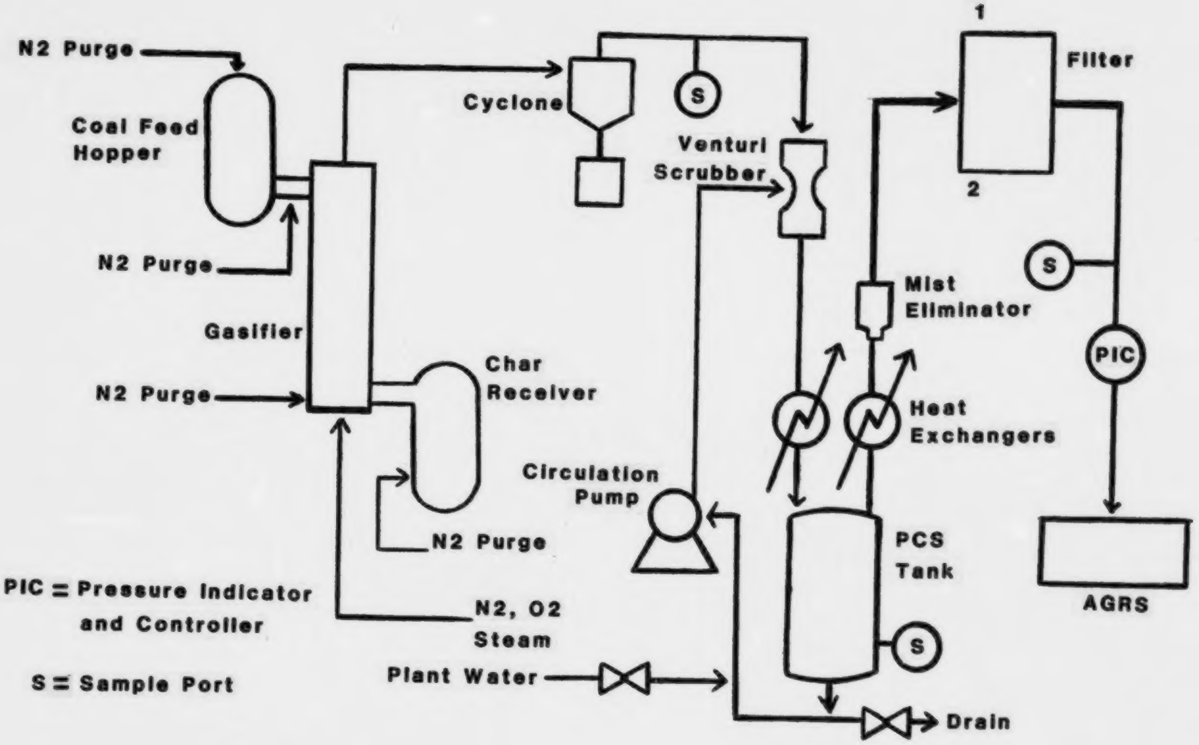
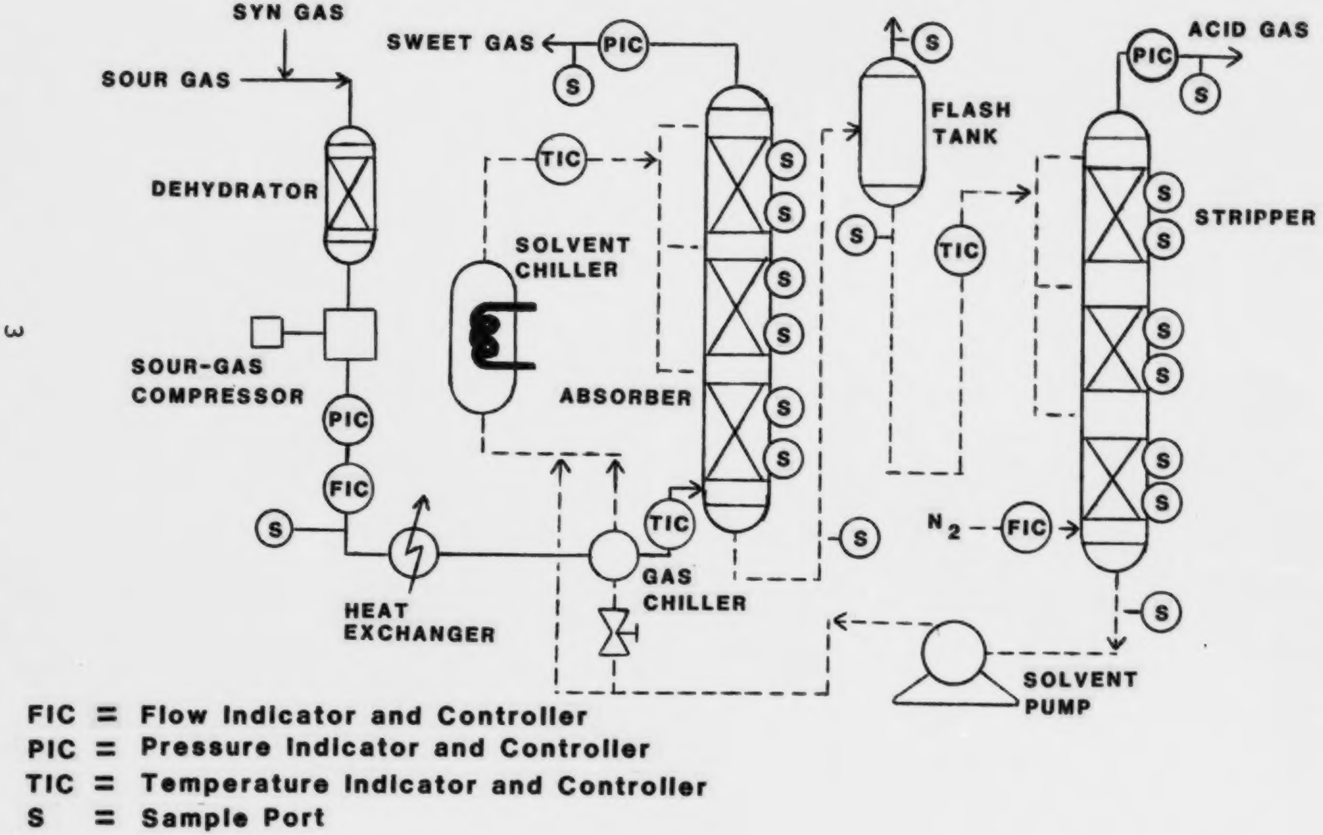

N2 Purge
Coal Feed Hopper
N2 Purge
Gasifier
N2 Purge
Cyclone
S
Venturi Scrubber
Char Receiver
N2 Purge
Circulation Pump
N2, O2 Steam
Plant Water
1
Filter
2
S
Mist Eliminator
Heat Exchangers
PIC
PCS Tank
S
AGRS
Drain
PIC = Pressure Indicator and Controller
S = Sample Port

FIGURE 2

Acid Gas Removal System (AGRS)


SYN GAS
SOUR GAS
DEHYDRATOR
SOUR-GAS COMPRESSOR
PIC
FIC
S
HEAT EXCHANGER
SWEET GAS
PIC
S
TIC
SOLVENT CHILLER
ABSORBER
S
TIC
GAS CHILLER
FLASH TANK
S
TIC
ACID GAS
PIC
STRIPPER
N_2
FIC
SOLVENT PUMP

FIC = Flow Indicator and Controller
PIC = Pressure Indicator and Controller
TIC = Temperature Indicator and Controller
S = Sample Port

development of operating and sampling procedures, and for the refinement of analytical methods. The results of the remaining runs on coal char are summarized in this report.

A computer program was written to reduce the voluminous plant and analytical data acquired in the course of a run to manageable proportions. Material balances about the gasifier were calculated for total mass and for major elements (C,H,O,N,S), as well as for three volatile and environmentally hazardous trace elements — arsenic, lead, and mercury.

A major effort was devoted to the calibration of all process sensors and flow meters, and to the gas analysis, to achieve closed mass balances around the gasifier-PCS system and the AGRS. This effort has enabled the consistent closure of material balances on major elements and total mass to within 5%.

The principal components of the make gas — carbon monoxide, hydrogen, methane, carbon dioxide, water vapor, and hydrogen sulfide— were monitored routinely; in addition, in several of the most recent of the runs performed, the make gas was analyzed for sulfur gases using flame photometry. Material balances were also obtained for the acid gas removal system, and CO_2 and H_2S removal efficiencies were determined for various operating conditions. The make gas and the wastewater were each analyzed for hydrocarbon content and were found to contain relatively small amounts of potentially hazardous species. This situation will change dramatically when a non-pretreated coal is used as the feedstock to the gasifier instead of the char used in the studies described in this report.

An important function of the gasifier is to provide a representative and reproducible feed gas to the PCS and acid gas removal systems. To enable the specification of gasifier operating conditions, a gasifier model was developed that treats the unit as a simple mixer, and incorporates kinetic rate laws for the principal gasification reactions, including the water gas shift. The model takes as input the reactant feed rates and operating conditions in the gasifier, and calculates the carbon conversion and product gas flow rate and composition.

This report includes summaries of operating conditions, conversions and removal efficiencies, and material balances for both the gasifier and acid gas removal systems; sulfur conversion data and concentrations of various sulfur gases in the make gas; data on emissions of the three hazardous trace elements cited above; and performance data for the acid gas removal system. In addition, the gasifier data reduction program is described, the principal features of the gasifier model are summarized, and model-based correlations of carbon conversion, make gas production, and make gas heating value with gasifier operating conditions are presented. Finally, plans for future studies using the facility are outlined.

CHAR GASIFICATION RESULTS

A total of 61 runs were completed using a Western Kentucky No. 11 coal char as feed stock. The first 13 of these runs were used primarily for the development of operating and sampling procedures, and refinement of analytical methods. The data from gasifier runs GO-14 through GO-61 have been collected and reviewed, and are included in this report. A schematic diagram of the gasifier-PCS system shown in Figure 1 and gives the location of the major sampling points for this part of the facility.

A summary of the principal experimental results is shown in Table 1. In processing the data from these runs, the purge nitrogen flow rate was adjusted to close the nitrogen balance on the gasifier. This was done to correct for recently discovered calibration errors in the nitrogen flowmeters, and for suspected purge nitrogen leakage in the system. The other quantities used in the run data analysis reflect actual operating and analytical data. The notation of yes or no in the last column of Table 1 indicates whether or not the mass balances were judged acceptable.

MASS BALANCES

The raw data for runs GO-14 through GO-61 were reduced using a data processing program to be described later in this report. Criteria for acceptance of a run were chosen following inspection of the mass balance results. A run is judged acceptable if the total mass recovery is within 5%, and if the worst of the recoveries of elements C, H, and O are within 8%. Based on these criteria, 27 of the 39 runs reviewed are acceptable, and are designated by crossed circles in correlation plots of the data and by YES's in Table 1. Points with filled circles are for runs with total mass recoveries within 5% and worst element recoveries within 6%. Open circles are used for all other runs, listed as not acceptable in Table 1.

The mass balance results noted above are based on the analysis of samples of solid, liquid, and gaseous streams. During operation, care is taken to make sure that steady state operation has been achieved before samples are taken.

Among other things, the data logging program provides a one page summary of run data, including run conditions, total mass and elemental material balances, and measured and predicted values of carbon conversion, make gas flow rate and heating value, and make gas constituent flow rates. Run summaries for runs GO-14 through GO-61 are given in Appendix A.

TABLE 1

SUMMARY OF CHAR GASIFICATION RUN DATA

Run	T(°F)	P(psig	Moles H_2O / Mole C	Solids Holdup (lb)	% C Conv	Dry Make Gas Rate (SCFM)	H.V. of Sweet Gas (Btu/SCF)	% Mass Rec	Worst % Rec	ΔT(°F)	Accept ?
GO-14	1790.3	103.0	0.63	14.6	37.5	13.44	267.0	103.7	116.8 (H)	8	NO
GO-15	1786.8	100.8	0.79	14.9	44.9	12.23	283.0	100.3	105.3 (H)	62	YES
GO-16	1778.8	98.8	0.70	19.8*	44.2	10.70	304.6	98.8	109.1 (H)	31	NO
GO-17	1778.6	102.0	1.15	15.0	30.5	13.00	332.2	103.3	116.8 (H)	26	NO
GO-18	1872.0	102.4	1.15	13.7	42.4	18.67	339.4	105.5	120.1 (H)	37	NO
GO-19	1761.3	101.9	0.97	23.3*	49.6	12.90	326.0	101.3	111.1 (H)	53	NO
GO-19A	1777.9	102.0	1.15	22.0*	59.6	13.38	323.3	100.5	106.8 (H)	26	YES
GO-20	1881.5	106.5	1.26	15.8*	104.3	21.36	321.7	101.4	107.3 (C)	19	YES
GO-22	1868.6	103.7	1.05	17.1*	99.5	17.58	313.3	100.5	106.6 (H)	37	YES
GO-24	1878.1	105.0	1.01	30.1	42.1	16.61	307.9	103.9	107.6 (H)	28	YES
GO-25	1862.2	101.7	1.13	26.8	40.2	15.83	306.1	103.3	106.1 (H)	56	YES
GO-26	1714.3	101.0	1.00	24.0*	40.4	10.35	319.9	99.7	104.8 (H)	43	YES

* 52" bed

Runs 14 - 27
ΔT is for 10" - 40"

TABLE 1 (cont.)

SUMMARY OF CHAR GASIFICATION RUN DATA

Run	T (°F)	P(psig)	Moles H2O / Mole C	Solids Holdup (lb)	% C Conv	Dry Make Gas Rate (SCFM)	H.V. of Sweet Gas (Btu/SCF)	% Mass Rec	Worst % Rec	△T(°F)	Accept ?
GO-28	1820.5	104.0	1.28	17.3	56.9	17.08	335.9	103.5	107.7 (O)	31	YES
GO-29	1816.5	104.0	1.13	24.3*	47.1	16.97	335.9	94.2	87.9 (C)	58	NO
GO-30⁺	1830.2	103.5	1.27	14.6	50.9	16.19	336.0	99.3	93.3 (C)	21	YES
GO-31⁺	1832.7	106.2	1.03	15.5	39.9	19.11	340.1	102.4	106.7 (H)	22	YES
GO-34	1693.7	103.9	0.73	22.2	16.4	10.74	196.6	97.6	107.4 (H)	46	YES
GO-35	1683.0	103.4	0.94	21.1	22.2	10.54	273.5	100.0	106.8 (H)	51	YES
GO-36	1782.8	104.7	0.68	19.1	26.2	15.18	243.1	98.8	118.0 (H)	49	NO
GO-37	1786.9	105.4	1.31	17.3	32.9	14.71	314.4	97.6	109.1 (H)	39	NO
GO-38A	1829.7	104.9	1.33	15.9	56.0	16.72	323.7	95.5	94.3 (O)	36	YES
GO-38B	1829.8	104.6	1.33	15.9	54.3	16.22	324.7	95.6	95.6 (O)	33	YES
GO-43	1819.6	104.5	1.31	16.8	65.1	17.25	319.0	103.7	92.2 (H)	35	YES
GO-44B	1699.8	101.6	1.31	18.4	31.6	11.73	296.0	98.9	101.8 (H)	36	YES

+ 6 cone distributor

* 52" bed

GO-28 →
ΔT is for 10" - 35"

TABLE 1 (cont.)

SUMMARY OF CHAR GASIFICATION RUN DATA

Run	T(°F)	P(psig)	Moles H2O / Mole C	Solids Holdup (lb)	% C Conv	Dry Make Gas Rate (SCFM)	H.V. of Sweet Gas (Btu/SCF)	% Mass Rec	Worst % Rec	ΔT(°F)	Accept ?
GO-27	1806.7	106.1	1.32	14.4	51.2	18.17	315.9	103.7	107.2 (C)	13	YES
GO-45	1696.6	103.1	0.81	20.4	20.3	15.97	121.7	99.1	103.1 (H)	44	YES
GO-46	1822.7	103.5	0.88	16.6	42.8	17.51	212.7	96.3	90.0 (C)	39	NO
GO-47	1814.6	104.2	0.82	17.3	42.9	18.41	216.9	97.0	95.6 (H,O)	50	YES
GO-48	1818.3	103.8	1.33	16.3	54.2	16.38	315.5	102.2	104.6 (C,H)	43	YES
GO-49	1818.3	78.4	0.83	15.1	46.6	13.70	294.1	103.2	88.6 (H)	25	NO
GO-51	1815.3	78.2	0.83	16.7	40.0	13.07	305.1	104.0	108.7 (O)	50	NO
GO-53	1818.7	104.2	0.98	16.7	40.7	18.88	336.0	101.2	119.4 (H)	54	NO
GO-55	1738.8	77.5	1.05	16.5	37.0	11.67	315.3	101.8	106.0 (C)	29	YES
GO-56	1825.1	104.0	1.55	15.3	55.3	16.61	329.3	98.2	97.9 (H)	26	YES

Note: Runs 21, 23, 32, 33, 39-42, 50, 52, and 54 not included due to equipment failures

TABLE 1 (cont)

SUMMARY OF CHAR GASIFICATION RUN DATA											
Run	T(°F)	P(psig)	Moles H2O / Mole C	Solids Holdup (lb)	% C Conv	Dry Make Gas Rate (SCFM)	H.V. of Sweet Gas (Btu/SCF)	% Mass Rec	Worst % Rec	△T(°F)	Accept ?
GO-57	1825.5	104.1	1.30	15.6	56.2	16.23	333.3	98.8	92.5 (H)	67	YES
GO-58	1814.3	102.6	1.08	16.3	51.6	15.01	321.9	102.8	107.6 (C)	55	YES
GO-59	1831.0	104.6	1.37	15.6	52.1	16.69	344.5	98.4	97.6 (H)	38	YES
GO-60	1817.6	103.4	0.83	17.5	30.5	15.81	261.5	101.7	93.7 (C)	54	YES
GO-61	1847.9	104.5	1.49	16.9	46.7	15.81	325.9	96.4	92.5 (C)	29	YES

TEMPERATURE EFFECTS

The effect of the average bed temperature on the dry, nitrogen-free make gas flow rate is shown in Figure 3. For the points shown, the molar steam to carbon ratio varied from 0.92 to 1.25. The plot indicates that the make gas flow rate is highly sensitive to the average bed temperature, with scatter due mainly to the small steam to carbon ratio differences and differing feed rates. The high sensitivity makes determination of the average bed temperature crucial for good model predictions.

The effect of temperature on carbon conversion cannot be shown clearly due to the coupled effects of other variables, such as gas velocities and coal feed rate, which were difficult to hold constant from one temperature to another. However, the model for coal gasification developed in this study does a reasonably good job of correlating the data, including temperature effects, as will be shown subsequently.

STEAM TO CARBON RATIO EFFECTS

The effect of the steam to carbon ratio on the make gas flow rate is shown in Figure 4. At any given temperature the effect of increasing the steam rate at a given carbon input is to increase the make gas flow rate. A side benefit to operating with relatively high steam to carbon ratios in the fluidized bed gasifier is a reduced tendency for the char to clinker. During runs GO-14, 15, and 16, for which the steam to carbon ratio was less than 0.8, it was not uncommon for the removal screw to jam because of a clinker lodging in the removal screw housing. During the remainder of the runs, with the steam to carbon ratio greater than 0.8, few problems arose due to clinker formation.

The effect of steam to carbon ratio on carbon conversion cannot be shown clearly for the reasons given in the previous section on temperature effects.

SULFUR CONVERSION

Measured sulfur conversion, is plotted vs carbon conversion in Figure 5. In most cases the sulfur conversion is greater. It is assumed to equal the carbon conversion by the model to be described later. Studies are currently under way to put the estimation of sulfur gas emissions on a firmer theoretical foundation.

MODEL RESULTS

The development of a mathematical model of the fluidized bed gasifier is described in detail in a later section of this report. The methods used for the determination of the optimal parameters for use in the model are also described.

Figure 3

THE EFFECT OF THE AVERAGE BED TEMPERATURE ON THE MAKE GAS FLOW RATE (DRY, N_2 FREE)

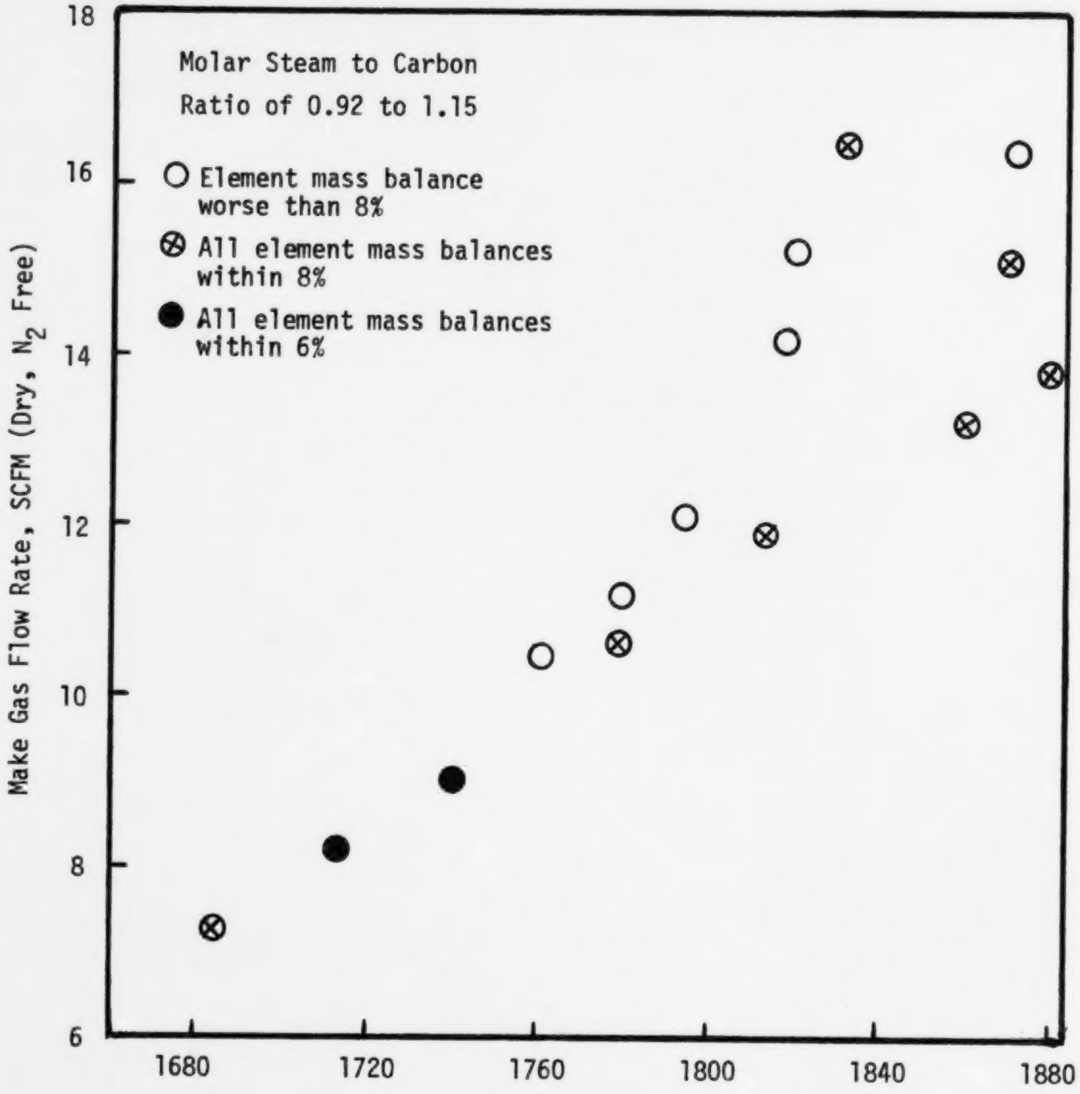


Figure 4

THE EFFECT OF THE STEAM TO CARBON RATIO

ON THE MAKE GAS FLOW RATE (DRY, N_2 FREE)

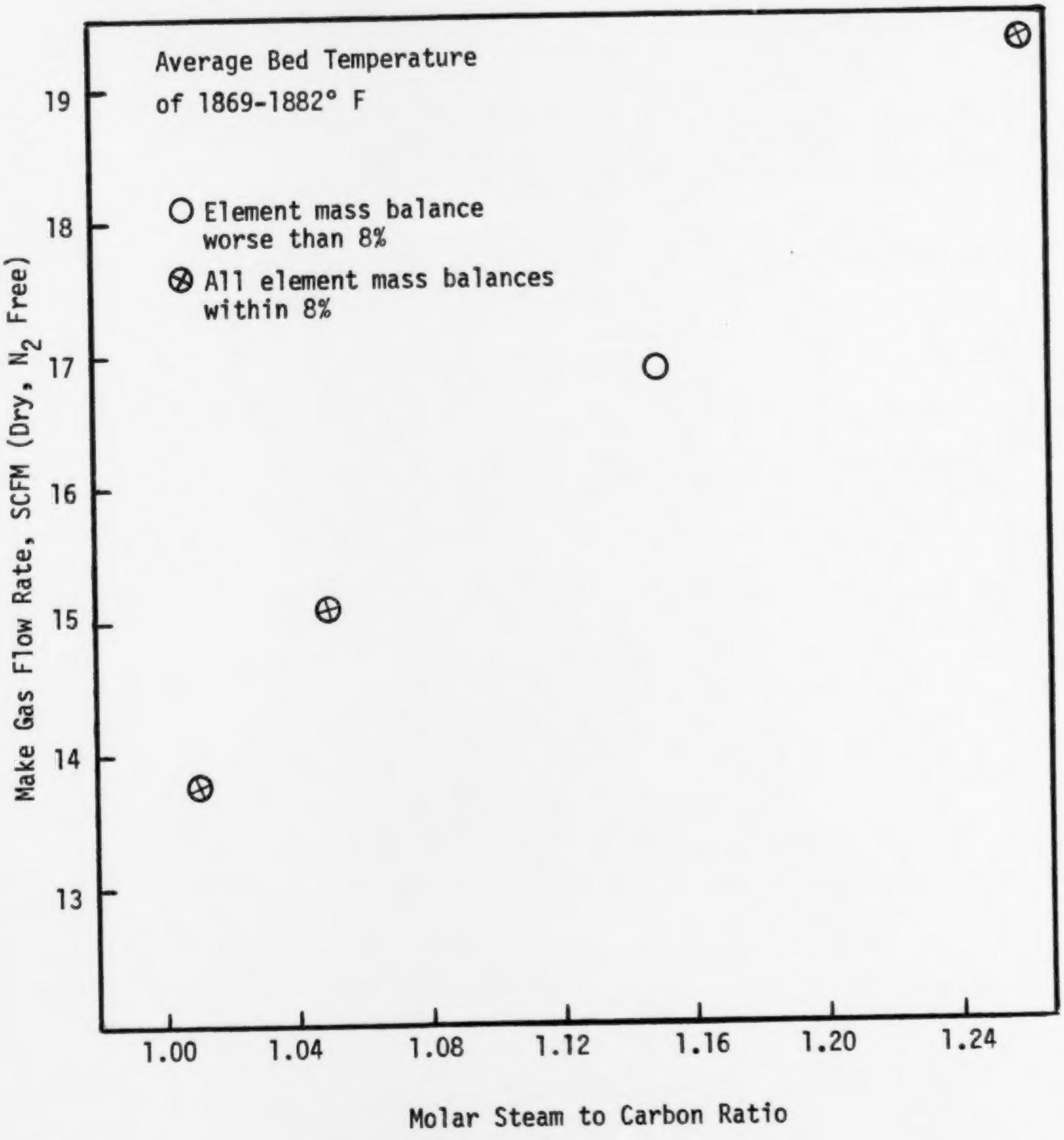
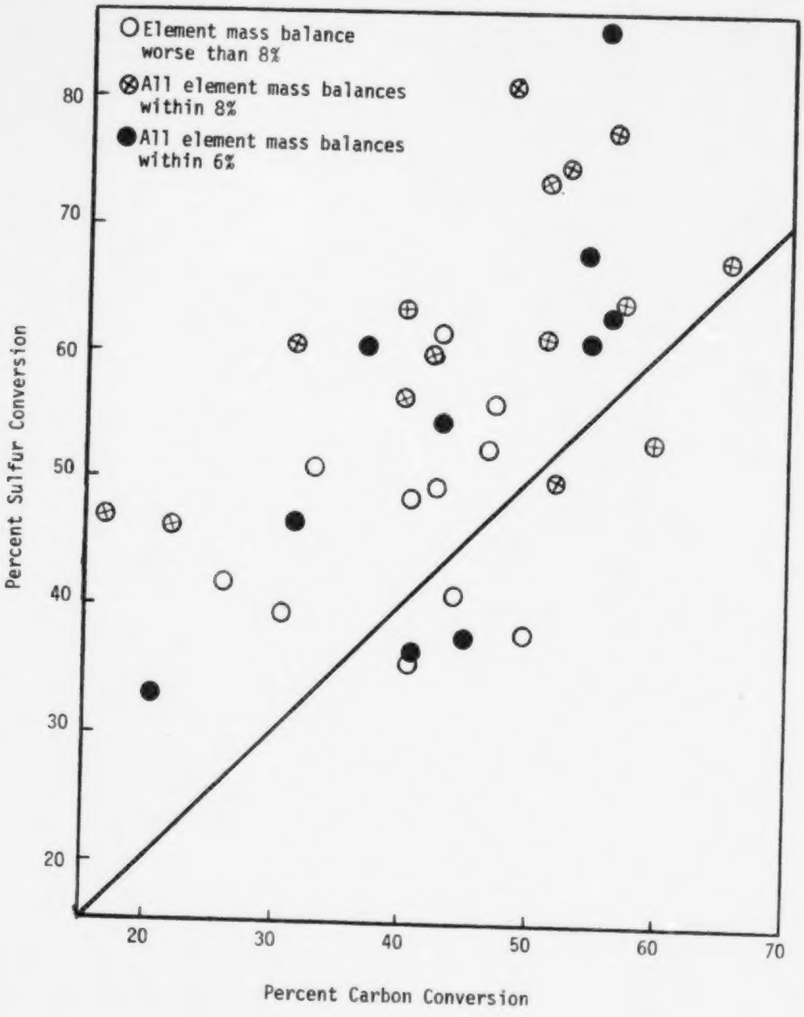


Figure 5

COMPARISON OF PERCENT SULFUR CONVERSION

TO PERCENT CARBON CONVERSION



Using the optimal parameter values, the model was run for gasifier runs GO-14 through GO-61. A representative model output is shown for run GO-44B in Table 2. Plots of predicted vs measured values of carbon conversion, dry make gas flow rate, and sweet gas heating value are shown in Figures 6 - 8. The reasonably close proximity of most points to the 45 degree line is gratifying in view of the crudeness of the model. The proximity of the points corresponding to the "best" runs (from the standpoint of satisfying mass balances) is even more satisfying.

For each run, the ratio

$$K = ([CO_2][H_2])/([CO][H_2O]) \qquad (1)$$

was calculated, where [ ] is the mole fraction of the evaluated species in the product gas. This quantity would equal the water-gas shift equilibrium constant at the reactor temperature if this reaction proceeded to equilibrium. A plot of the predicted vs experimental values of this ratio, K, is given in Figure 9. The degree of scatter may be attributed equally to the simplicity of the model, and to the fact that the mole fractions which are the constituents of K are interdependent, so that an experimental error in one of them affects the values of the others.

The significance of this plot emerges when it is compared with Figure 10, which shows the values of K predicted assuming shift equilibrium. This assumption leads to the overprediction of K by as much as a factor of two, and lends support to the conclusion that the shift reaction should not be assumed to proceed to equilibrium.

Table 2

```
                        *********************************
                        *                               *
                        * WELL-MIXED CHAR GASIFICATION  *
                        *                               *
                        *         MODEL RESULTS         *
                        *                               *
                        *********************************

                         GO-44B  1-22-80  11:15-14:30
REACTOR SPECIFICATIONS                       FEEDRATES(LB/HR)

BED PRESSURE(PSIG)      101.60               INLET CHAR              34.69
BED TEMPERATURE(F)     1699.80               STEAM                   55.85
SOLIDS HOLDUP(LB)        18.40               OXYGEN                  10.10
BED HEIGHT(IN)           38.00               NITROGEN                 6.32
BED DIAMETER(IN)          6.00               HYDROGEN                 0.00
BED VOIDAGE               0.74               PURGE N2                14.16

MODEL PARAMETERS                             FEED CHAR ANALYSIS(WT PERCENT)

PRETREAT TEMP(F)       2000.00               CARBON                  82.00
CHAR REACTIVITY         0.5000               HYDROGEN                 0.50
COMBUSTION EXTENT       0.9500               OXYGEN                   3.90
SHIFT REACTIVITY    9.900E-06                NITROGEN                 0.10
                                             SULFUR                   2.60
                                             ASH                     10.80
                                              MODEL    EXPERIMENTAL

          DRY GAS FLOW RATE (SCFM)            12.04      11.73

          STEAM CONVERSION                    0.171      0.153

          CARBON CONVERSION
            COMBUSTION                        0.140
            GASIFICATION                      0.187
            TOTAL                             0.327      0.316

          ASH CONTENT OF CHAR                 15.24      12.00

          CHAR REMOVAL RATE (LB/HR)           23.07      21.80
                        GAS COMPOSITION (MOLE PERCENT)

                                 MODEL   EXPERIMENTAL

                        CO        6.76      6.60

                        H2       10.85     10.11

                        CH4       0.56      0.89

                        CO2       9.59      8.82

                        N2       15.96     15.91

                        H2S       0.19 *    0.28     (* ESTIMATED)

                        COS       0.00      0.01

                        H2O      56.08     57.38
```

Figure 6

PREDICTED VS. EXPERIMENTAL CARBON CONVERSION

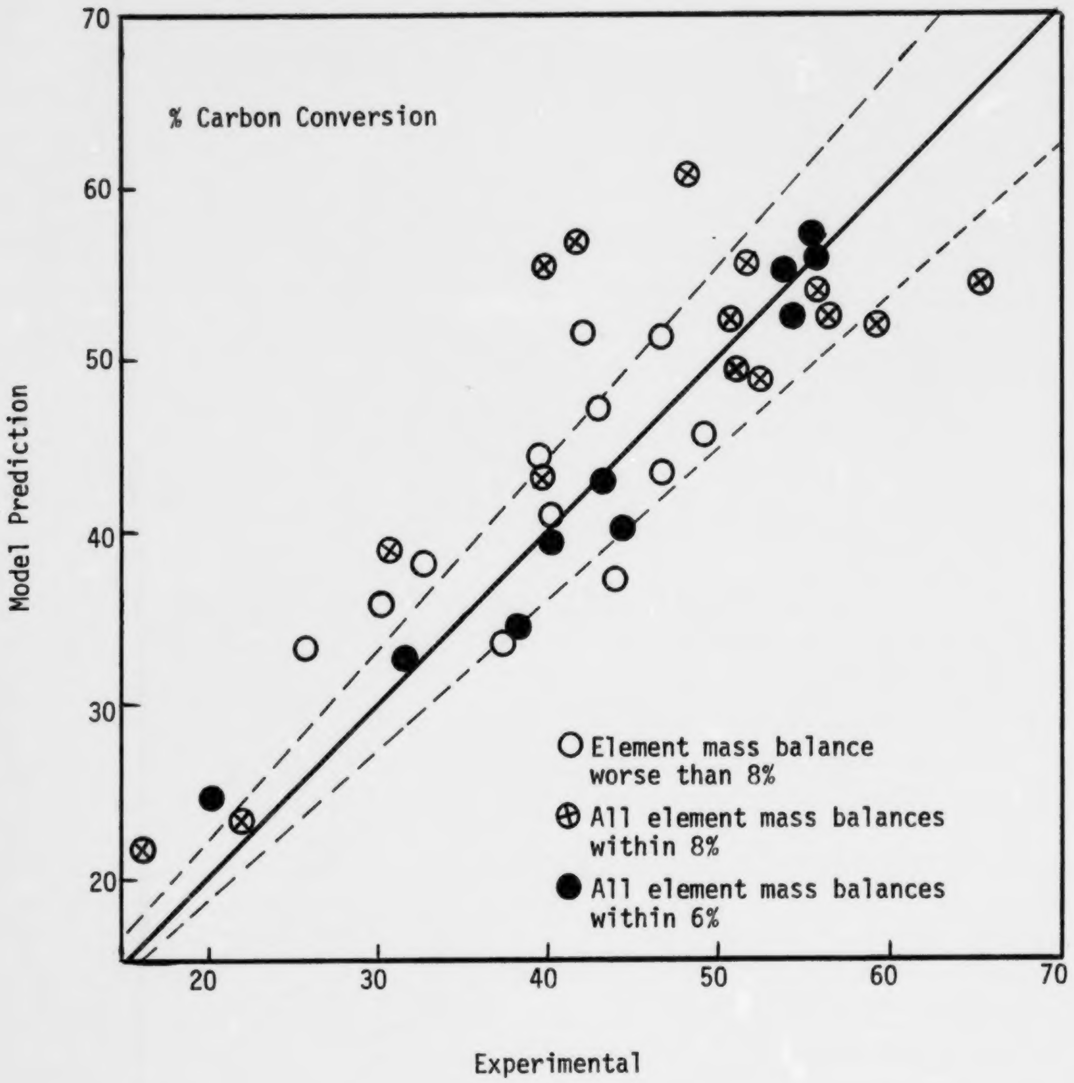


Figure 7

PREDICTED VS. EXPERIMENTAL DRY MAKE GAS FLOW RATE

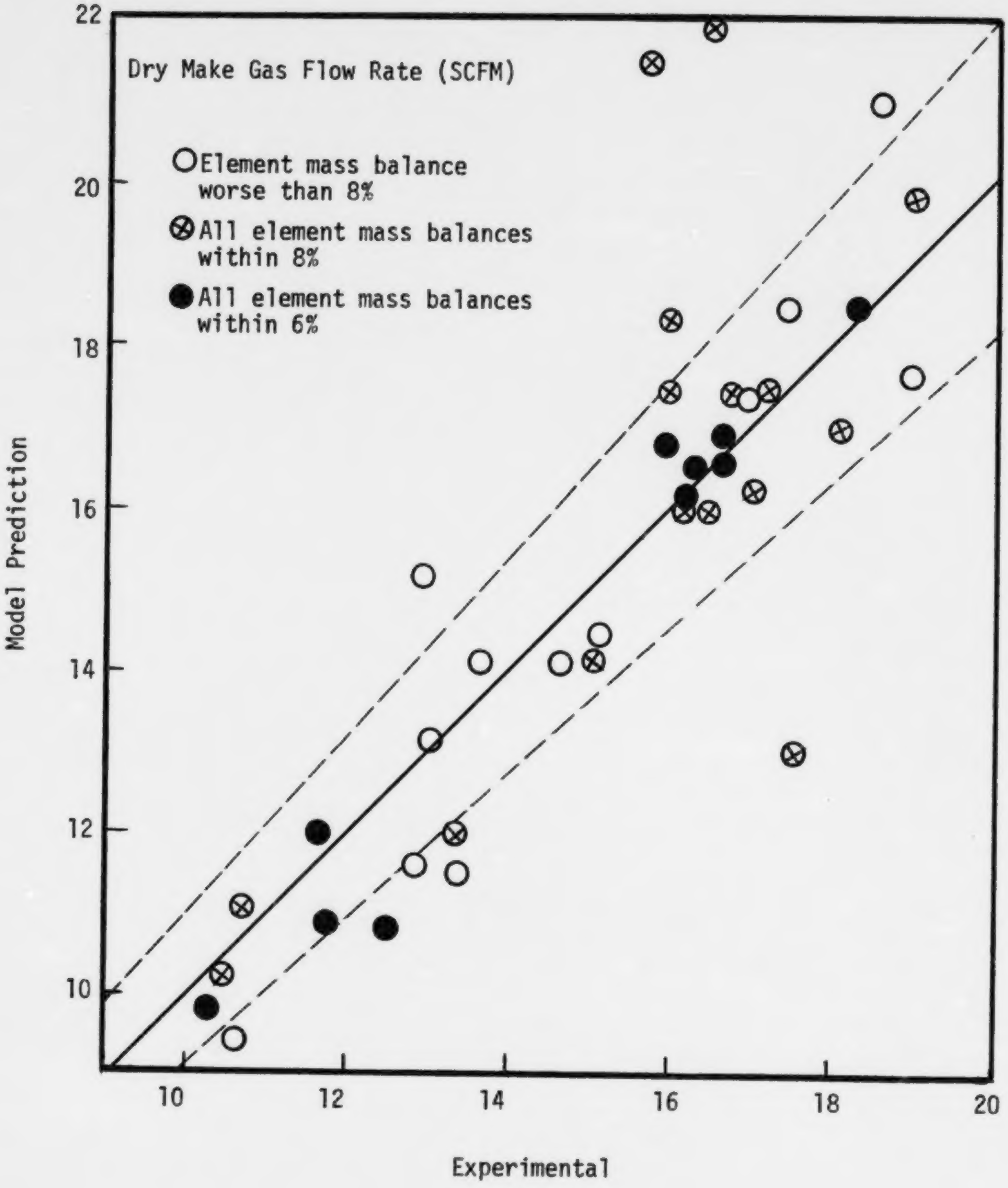


Figure 8

PREDICTED VS. EXPERIMENTAL HEATING VALUE OF SWEET GAS

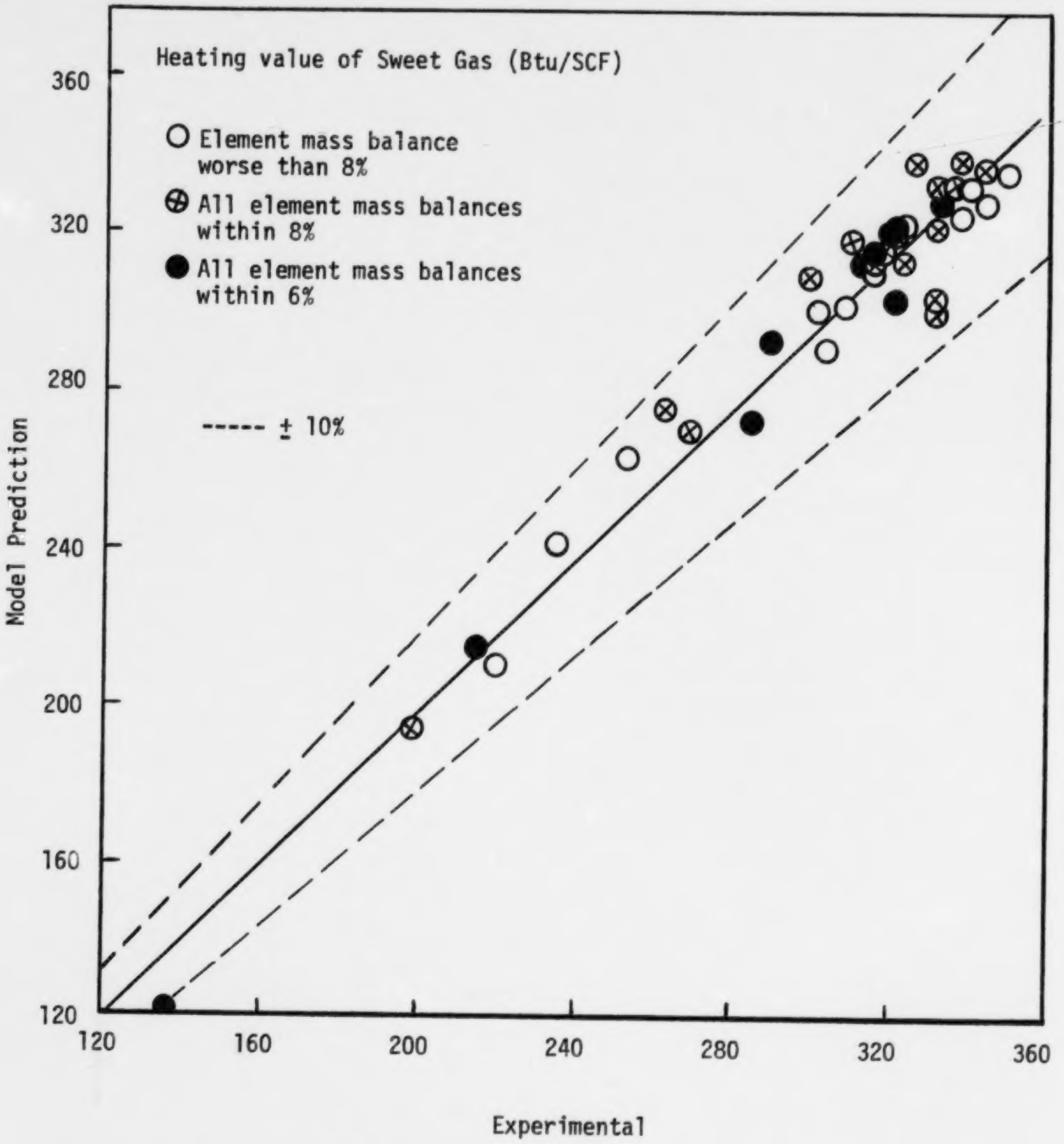


Figure 9

PREDICTED VS. EXPERIMENTAL K VALUE

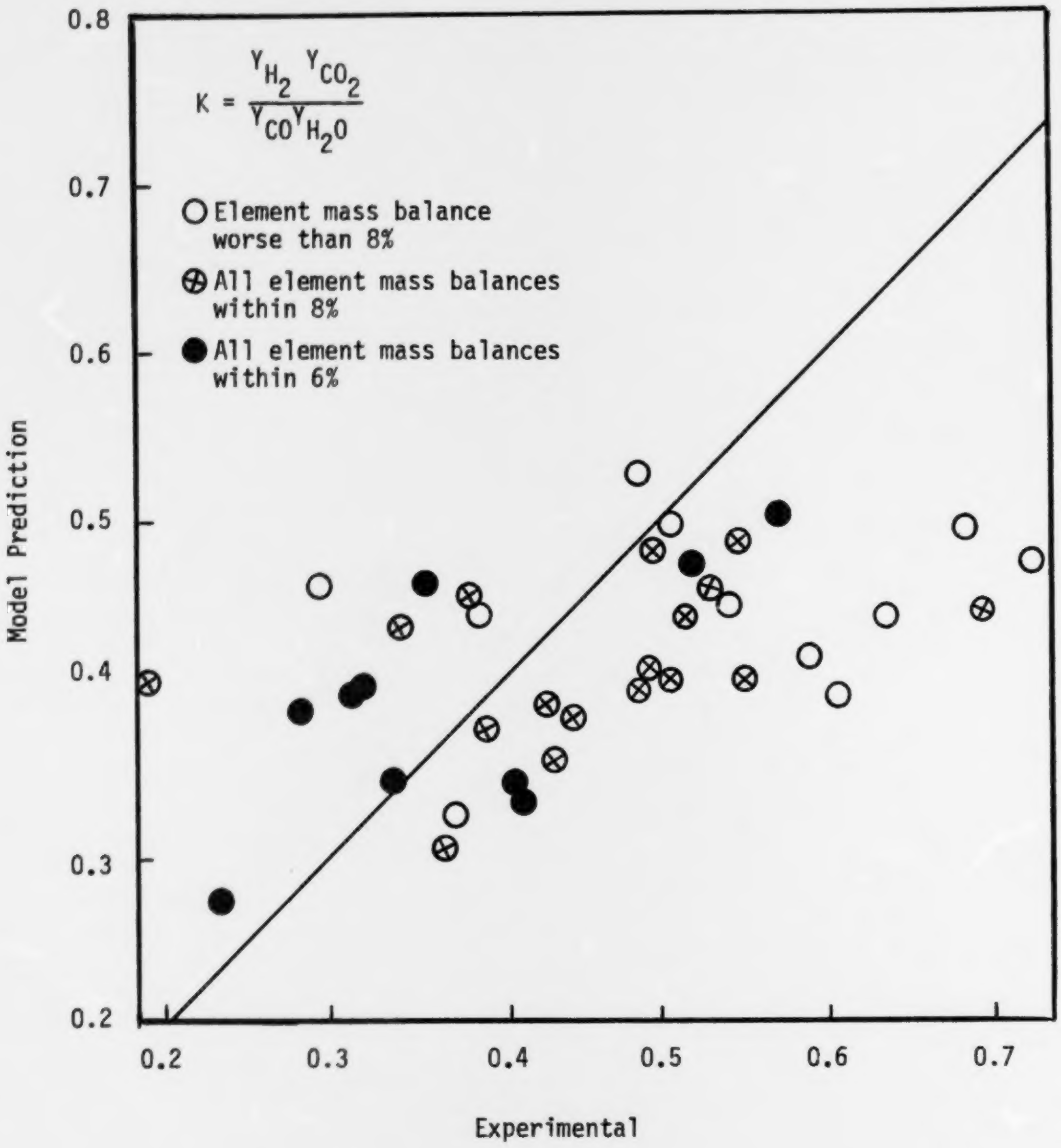
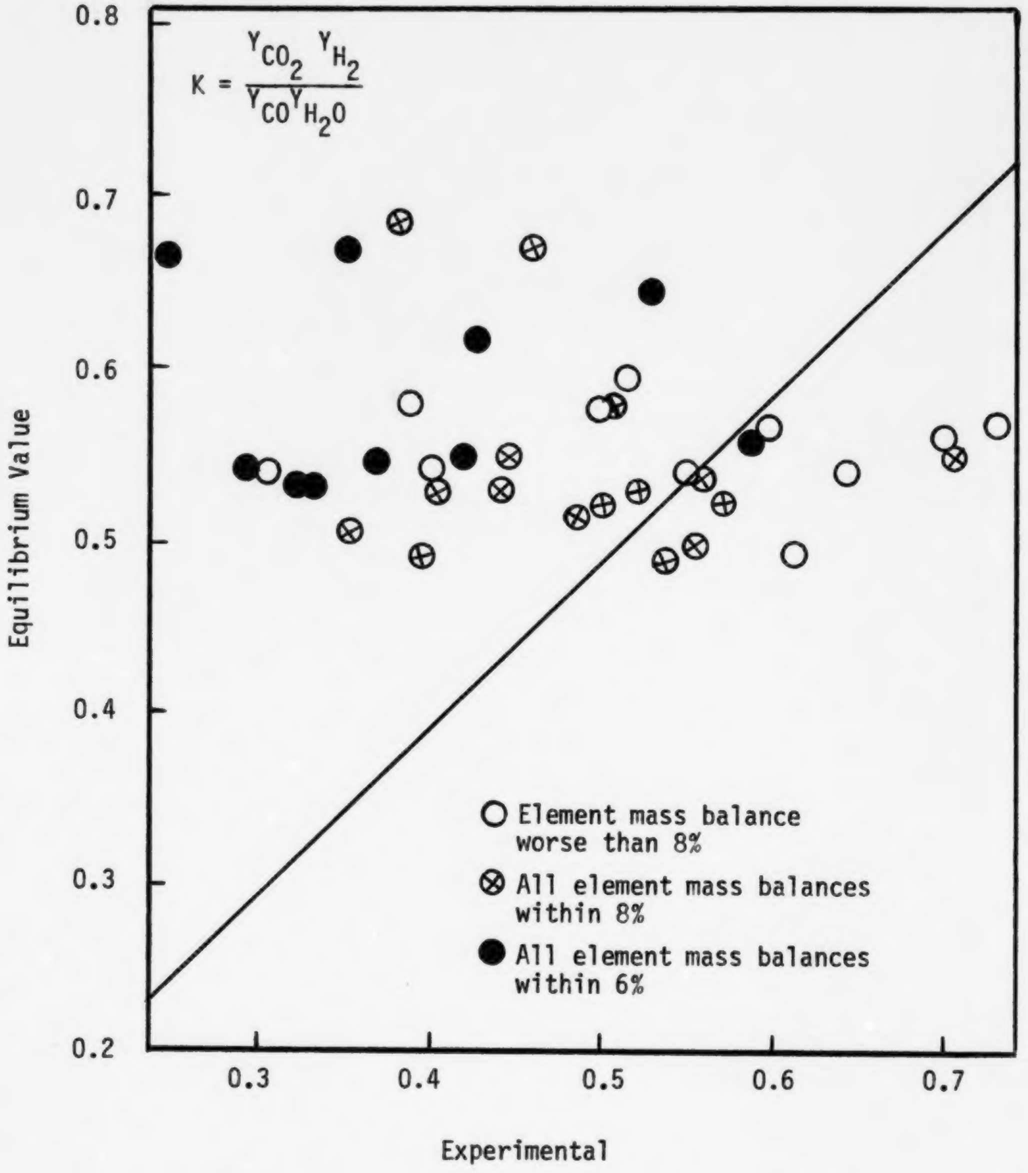


Figure 10

PREDICTED VS. EXPERIMENTAL K VALUE

ASSUMING SHIFT EQUILIBRIUM



SULFUR GAS AND HYDROCARBON EMISSIONS

Figure 11 shows an illustrative gas chromatogram obtained with a sample of make gas from one of the runs described above. The chromatogram was obtained on a Varian Model 3700 gas chromatograph equipped with a flame photometric detector, and a carbopak B 1/8" teflon column and shows the sulfur gas species present. Table 3 summarizes all measured sulfur gas concentrations. Samples were also analyzed by flame ionization detection, using a Tracor Model 550 gas chromatograph and a Teflon Carbopak B, 1.5% x E60 1% H_3PO_4, 6′ x 1/8" column. The only hydrocarbon detected in measurable quantities was methane.

Subsequent to the runs described in detail in this report, several gasification runs have been carried out using a non-pretreated New Mexico subbituminous coal as the feedstock.

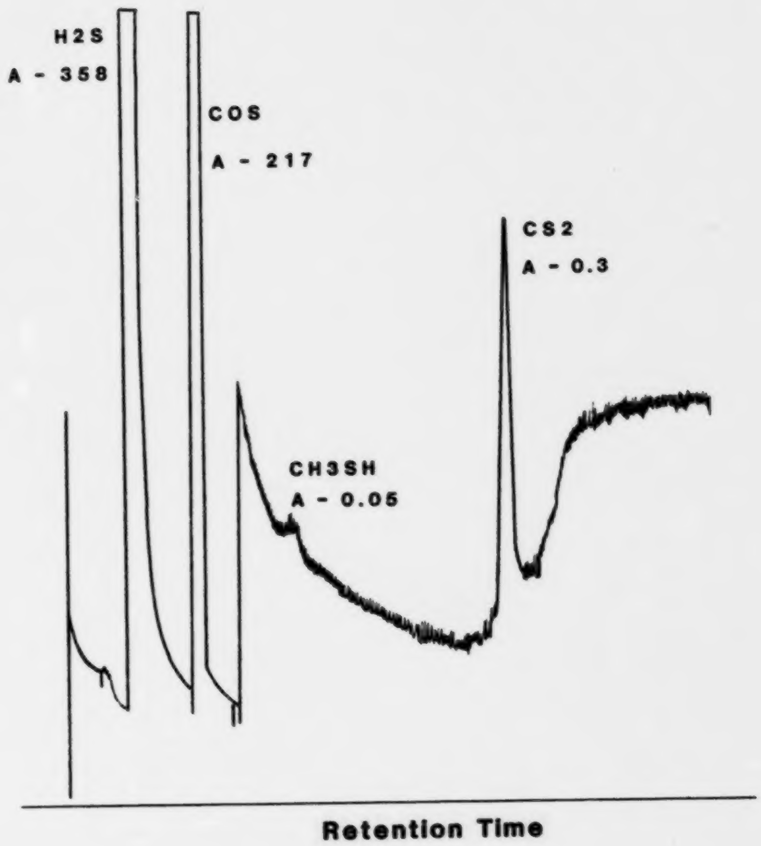
TABLE 3
CONCENTRATIONS OF SULFUR GASES IN REACTOR MAKE GAS

Run No.	Average Bed Temp. ^oF	Concentrations, ppm				
		H_2S	COS	CS_2	CH_3SH	Thiophene
43	1794	6229	277	2.27	x	x
44	1678	6510	283	2.44	x	N.D.
45	1671	3433	266	7.92	x	x
46	1790	5478	222	1.56	x	x
47	1785	5071	272	1.97	x	x
48	1778	6912	312	3.30	x	x
49	1799	7052	403	3.80	x	x
51	1777	6711	299	1.56	x	x
55	1708	8931	465	2.95	x	N.D.
56	1800	8924	410	1.58	x	x
57	1778	8098	388	1.58	x	x
58	1771	5111	362	1.36	x	x
59	1803	8470	306	1.61	x	x
60	1818	8887	332	2.43	x	x
61	1848	8611	333	3.00	x	x

x - less than 1 ppm
N.D. - none detected

Figure 11

SULFUR GASES FROM CHAR GASIFICATION



A Indicates Normalized Peak Area

Chromatograms obtained using make gas samples from one of these runs are shown in Figures 12 and 13. The contrast between these chromatograms with those obtained for the pretreated coal make gas is dramatic, and demonstrates the important role of pretreatment in determining the emissions that can be expected from coal conversion processes.

It should be noted that in both cases the coal or char is fed into the reactor several feet above the top of the fluidized bed. The coal particles thus have ample residence time in contact with hot product gas for devolatilization and pyrolysis reactions to take place. While this is not very important for char gasification, it will strongly influence the composition of product gases for coal.

The bituminous coal char used in the experiments with which this report is concerned has a volatile matter content less than 2%, and it is very likely that much of the sulfur is present as pyrrhotite (FeS).(Attar, 1978) In this case, during steam-oxygen gasification the sulfur will be hydrolyzed to form mainly hydrogen sulfide. (Tipton, 1980) Gas phase reactions then tend to bring the concentrations of the compounds CO_2, H_2O, H_2, H_2S and COS to equilibrium proportions.

The two principal gas phase reactions involving H_2S and COS are:

$$COS + H_2O \rightleftharpoons H_2S + CO_2 \qquad (2)$$

$$COS + H_2 \rightleftharpoons H_2S + CO \qquad (3)$$

The equilibrium constants for these two reactions are defined as follows:

$$K_1 = [H_2S][CO_2]/[COS][H_2O] \qquad (4)$$

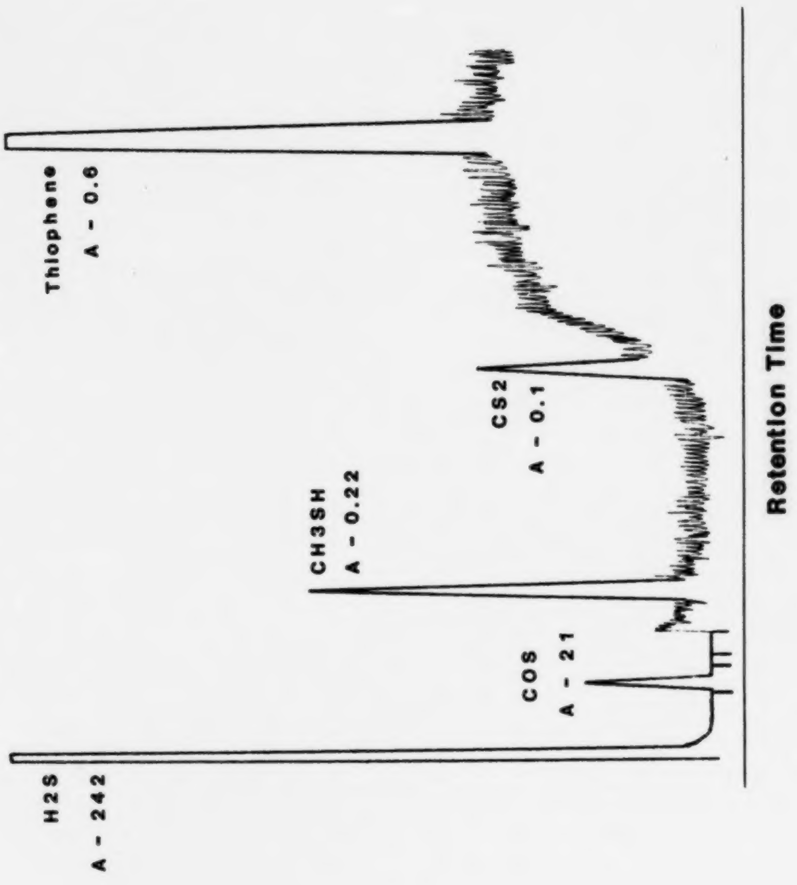
$$K_2 = [H_2S][CO]/[COS][H_2] \qquad (5)$$

Ideal gas behavior is assumed.

Figures 14 and 15 show values of K_1 and K_2 calculated from the gasifier make gas compositions, plotted versus the temperature at the top of the bed. Also shown on these figures are correlations of equilibrium constant data tabulated by Kohl and Riesenfeld (1979). Although there is considerable uncertainty in determining the correct value of the equilibrium constants because of complicating values of thermodynamic properties in the literature, and some inaccuracy in the experimental data, it appears that at the higher operating temperatures the compounds H_2S and COS are in equilibrium with H_2, CO, H_2O and CO_2 at the exit of the fluidized bed, and that the distribution of the effluent sulfur between H_2S and COS can be predicted if the sulfur conversion achieved in the gasifier is known. The deviation of the calculated values of K_1 and K_2 from the tabulated equilibrium constants at the lower temperatures suggests that the kinetics of Reactions (7) and (8) and possibly of other reactions involving sulfur gases should be taken into account when modeling sulfur gas evolution.

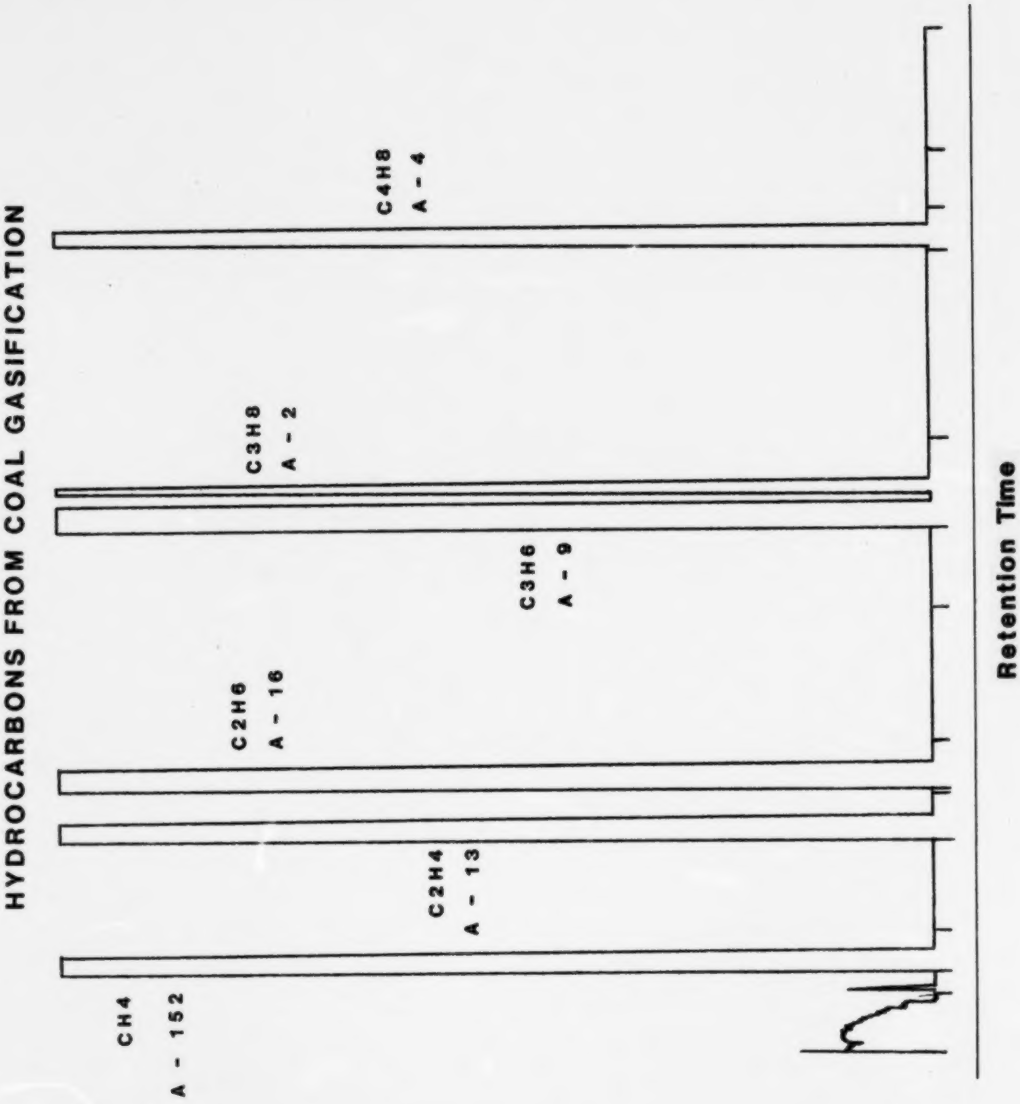
Figure 12

SULFUR GASES FROM COAL GASIFICATION



A Indicates Normalized Peak Area

Figure 13



A Indicates Normalized Peak Area

Figure 14

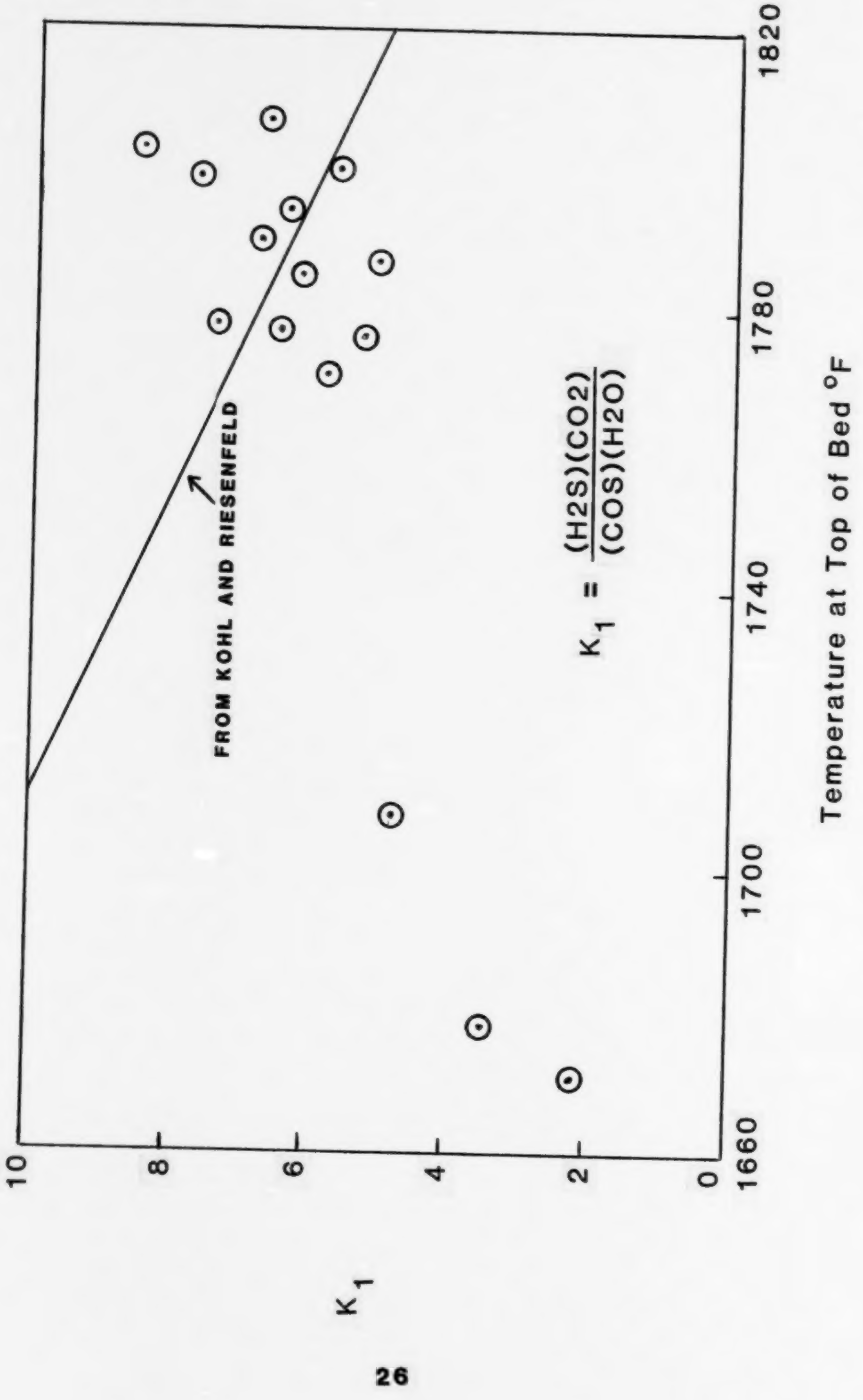
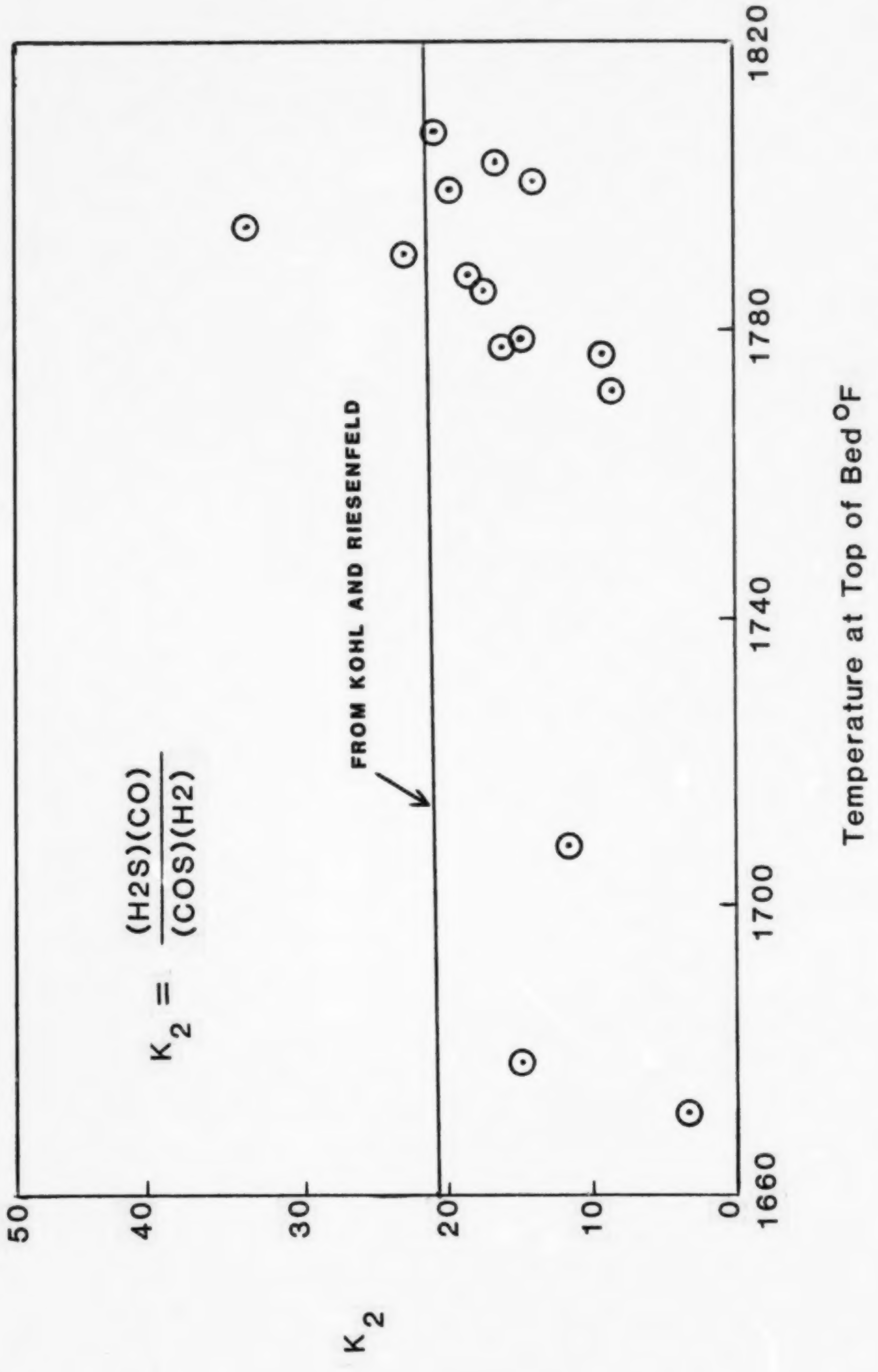

K1
10
8
6
4
2
0
1660
1700
1740
1780
1820
Temperature at Top of Bed °F
FROM KOHL AND RIESENFELD
K1 = (H2S)(CO2) / (COS)(H2O)

Figure 15


$K_2 = \frac{(H_2S)(CO)}{(COS)(H_2)}$
FROM KOHL AND RIESENFELD
K_2
0
10
20
30
40
50
1660
1700
1740
1780
1820
Temperature at Top of Bed °F

TRACE ELEMENT EMISSIONS AND BALANCES

SAMPLING SYSTEM

The process streams sampled were the feed coal, spent (bottom) char, cyclone dust, and make gas. Multiple samples of each stream were taken and analyzed during each of a series of gasifier runs. Procedures for sampling condensed streams were straightforward, and are described in detail by Ferrell et al.(1980a).

The gas sampling train, which is located downstream of the cyclone, is shown in Figure 16. A side stream of make gas is fed continuously through the train at a rate of 0.57 SCMH (20 SCFH). The stream passes through a condenser and filter to provide a cool dry gas stream and a condensate. Both high and low pressure ports are available for withdrawal of gas samples into steel or glass bombs.

After a preliminary set of runs in which a number of trace elements were analyzed, the decision was made to focus attention on three of the most volatile and potentially hazardous elements--arsenic, lead, and mercury. The sampling train shown in Figure 16 was incapable of trapping these elements to an acceptable extent. A second train was therefore designed for this purpose, to be placed in series with the first one.

Many train configurations and combinations of absorption and adsorption processes were tried, most of which were unsuccessful at recovering the elements in question. The recovery processes tried in these efforts included absorption in aqueous solutions of nitric acid, hydrogen peroxide, potassium permanganate, and sodium hydroxide, and adsorption on activated charcoal. Some of the failures were due to poor design, and others to interference by other species in the gasifier make gas. Descriptions of these attempts, and discussions of why they were unsuccessful, are provided by Trexler (1980).

It was tentatively determined that two independent recovery systems--one for mercury, and one for arsenic and lead--could achieve the desired collection efficiency, although further study will be needed to verify this conclusion. A solid sorption technique involving gold amalgamation (Kalb and Baldeck,1972) was selected for mercury collection and a liquid sorption method employing nitric acid solutions was selected to recover arsenic and lead. The final sample system design is depicted in Figure 17.

The arsenic-lead sample train receives as feed the cool dry gas from the cyclone exit sample train. The line connecting the two sample trains is extremely short to ensure minimal condensation as the gas cools. After a

Figure 16

CYCLONE SAMPLE TRAIN

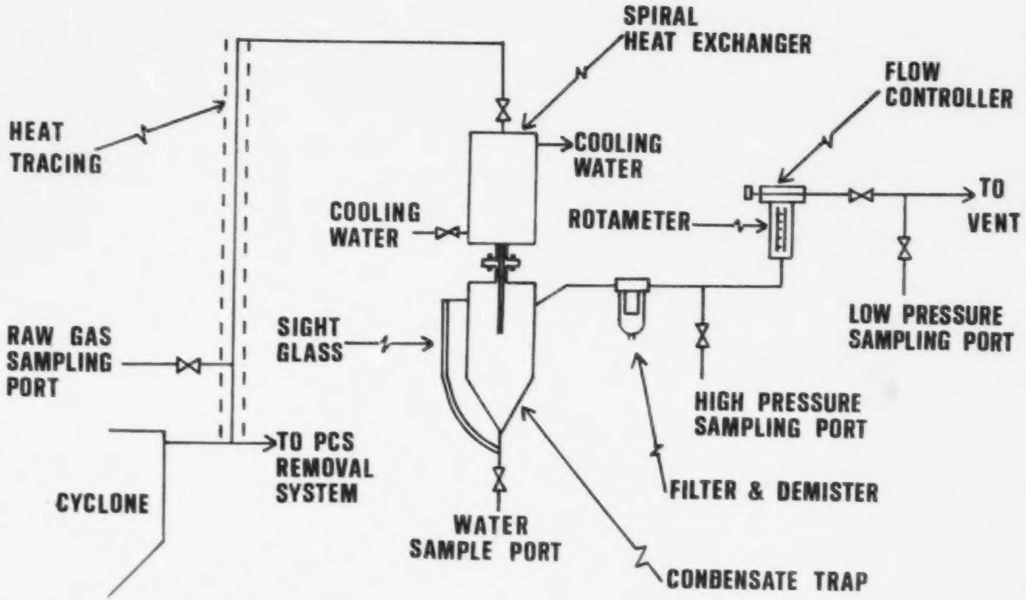

SPIRAL HEAT EXCHANGER
FLOW CONTROLLER
HEAT TRACING
COOLING WATER
COOLING WATER
ROTAMETER
TO VENT
LOW PRESSURE SAMPLING PORT
SIGHT GLASS
RAW GAS SAMPLING PORT
HIGH PRESSURE SAMPLING PORT
TO PCS REMOVAL SYSTEM
CYCLONE
FILTER & DEMISTER
WATER SAMPLE PORT
CONBENSATE TRAP

Figure 17

Trace Element Sample System

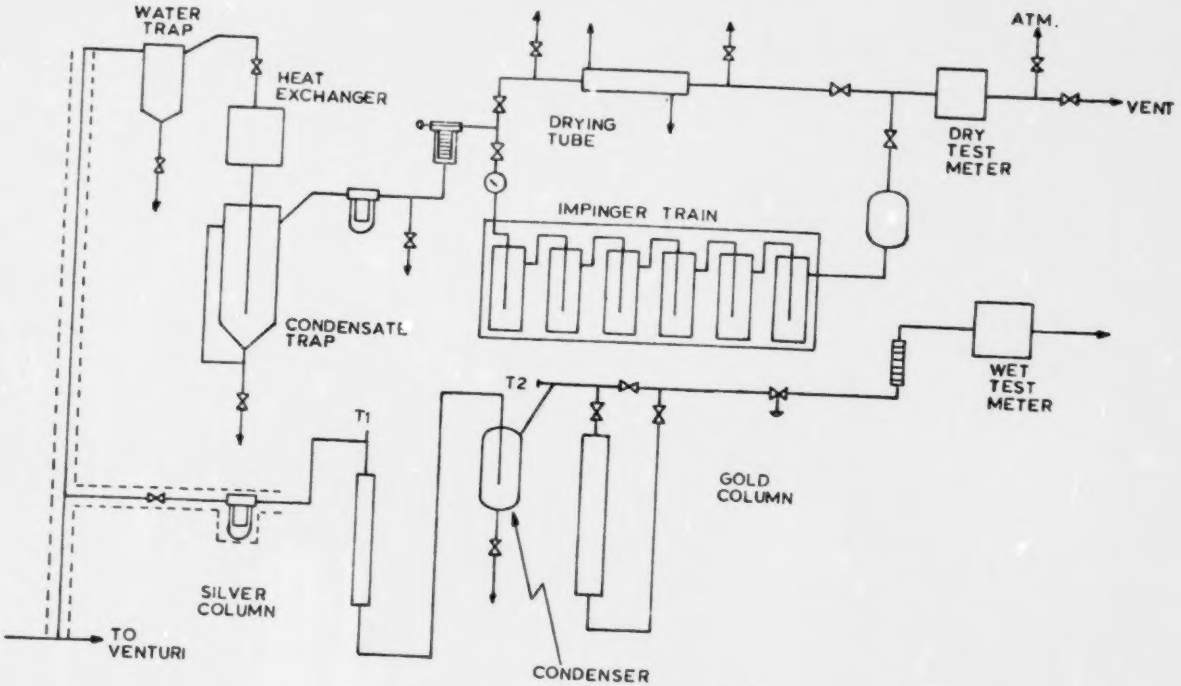

WATER TRAP
HEAT EXCHANGER
DRYING TUBE
ATM.
VENT
DRY TEST METER
IMPINGER TRAIN
CONDENSATE TRAP
WET TEST METER
T2
T1
GOLD COLUMN
SILVER COLUMN
TO VENTURI
CONDENSER

Figure 4.5 Trace Element Sample System

run, the line is rinsed with nitric acid and the rinse is collected for analysis. The dry gas enters a sample train which consists of a series of six impingers contained in an ice bath to enhance gas solubility. The first impinger is dry and is intended for removing condensables; it is followed by five impingers containing 250 ml each of 10% nitric acid for the oxidative dissolution of arsenic and lead. The impinger solutions, rinses, condensate water, and the high pressure filter are all subjected to analysis, the latter after digestion in concentrated nitric acid. A blank filter is also digested and analyzed.

The mercury recovery system receives a small sample stream of unconditioned gas directly from the cyclone exit. The system consists of a filter for particulate removal, a silver catalytic oxidizer, a water trap, a gold amalgamator, and a wet test meter for gas flow rate measurement. The silver column serves to oxidize hydrocarbons and sulfur species, which would otherwise interfere with the gold amalgamation reaction. The temperature of the oxidizer must be above 280°C to prevent the amalgamation of the mercury with the silver, and the temperature of the gas stream entering the gold column must be less than 280°C to allow the gold amalgamation reaction to take place.

OPERATION OF THE TRACE ELEMENT SAMPLING SYSTEM

The cyclone exit sample train is turned on when steam is fed to the gasifier with both trace element sampling systems being bypassed. Initial test meter, temperature, pressure and time readings are recorded. One hour after the gasifier achieves steady state it is assumed that the PCS system has also done so, and flow through the first sampling train is commenced. The sample train continuously receives a small sample of the cyclone exit gas. The water in the stream is condensed and the gas is then filtered, dried, passed through a dry test meter and vented. Water samples are taken and weighed, and flow rates are recorded throughout the run to allow the gravimetric determination of the water content of the cyclone exit gas stream. The water samples taken over the steady state period are combined in a sample bottle.

When the PCS system attains steady state, gas samples are collected in evacuated bombs from the various sample ports. After these samples are taken the gas pressure and time readings are recorded, and the flow is diverted through the arsenic-lead recovery train. After approximately five hours the sampling is stopped by rerouting the gas back to the drying tube and the test meter readings are recorded.

Approximately two hours after the PCS system has attained steady state, the mercury sampling system is turned on. This system receives a small sample stream of about 0.03 SCMH directly from the cyclone exit. The valve configuration is such that the flow bypasses the gold amalgamator. The sample stream entering the silver oxidizer is monitored and the temperature is maintained at 300°C using heating tape. After the gas flow rate and temperature appear stable, the sample stream is routed through the gold amalgamator. The initial test meter readings are recorded, and sampling is allowed to take place for about 15 minutes. When the shut-off valve is turned off, the final test meter readings are taken.

After shutdown, the arsenic-lead recovery train impingers are disconnected and all lines are rinsed. Each rinse is combined with the solution from the subsequent impinger. The first impinger is rinsed with a known volume of nitric acid, the volumes of each impinger condensate and rinse are determined, and the solutions are stored for analysis. The high pressure filter is removed from its cartridge and digested in nitric acid. The gold amalgamation column is removed from the line and connected to a series of potassium permanganate impingers, and the mercury is thermally desorbed under nitrogen flow at a temperature above 280°C. The potassium permanganate solutions are stored for subsequent analysis.

ANALYSIS

Trace element analyses were carried out using a Perkin Elmer Model 603 Atomic Absorption Spectrophotometer. An HGA-2200 graphite furnace was used for arsenic and lead analysis, and a cold vapor generation system was used for the analysis of mercury. Ramp heating was used for the drying and charring steps, and normal temperature-controlled or time-controlled heating and deuterium background correction were used for the analysis of arsenic and lead. Electrodeless discharge lamps were used in all cases.

The analysis procedure was basically the same for each element. Standard linearity was established for the range the samples fell in. If the standards showed curvature, the samples were diluted. National Bureau of Standards-certified coal samples were analyzed concurrently with the run samples to ensure accuracy of analysis. If the analysis of the NBS standard did not agree with the certified value, the entire lot of analyses was discarded and new analyses were made.

All of the furnace and spectrophotometer operating parameters were optimized to give the highest possible signal-to-noise ratio. The resulting values are presented in Table 4. The absorption wavelength used in the arsenic determination was 197.2 nm instead of the more commonly used wavelength of 193.7 nm. This change eliminated severe background interference from overlapping carbon absorption (Eddinger and Fernandez, 1980). Direct calibration was used for the determination of mercury, and the method of standard additions was used for the analysis of arsenic and lead. Nickel complexation was used to allow high temperature charring in the analysis of arsenic.

The most serious problem encountered in the analyses was matrix interference from the coal ash. This problem was particularly acute in the analysis of arsenic. However, the wavelength change cited above minimized the interference and increased the accuracy of analysis.

TABLE 4
ATOMIC ABSORPTION ANALYSIS PARAMETERS

Element	Dry Temp-Time	Char Temp-Time	Atomization	Wavelength	Slit
	Ramp Time	Char Time	Temp Time		
	°C-sec/sec	°C-sec/sec	°C-sec	nm	nm
As	125-30 ------ 10	1000-30 ------- 10	2700-8	197.2	0.7(4)
Hg	COLD VAPOR ANALYSIS			253.5	0.7(4)
Pb	125-40 ------ 10	600-34 ------ 10	2300-8	217.0	0.7(4)

RESULTS

Trace Element Concentration Variations in Feed Coal

Toward the end of the gasification runs, it was noted that the trace element concentration of the feed coal sometimes differed from run to run. Since more than one drum of feed is used to load the feed hopper, this result suggested that the trace element concentration of the inlet stream might be varying with time. The single grab sample taken after every run would not reflect this variation, and errors would consequently occur in attempts to close a steady state mass balance around the gasification system.

To examine the variation in feed coal composition, samples of approximately 50 g each were taken from two locations (top and bottom) within each of eight drums. From these samples, two one-gram aliquots were subjected to oxygen bomb combustion. The resulting ash was analyzed for arsenic, mercury and lead content, and the results were subjected to a two-way analysis of variance to determine the significance of concentration variations within and between drums. The details of these calculations are given by Trexler (1980).

The analysis of variance indicated that there is no statistically significant effect of position within a drum on the concentration of arsenic, lead or mercury, but a significant variation was observed between drums at the 5% level of significance. This conclusion confirms the hypothesis that the trace element concentration is not uniform with time during a run, a fact that greatly increases the difficulty of closing a trace element mass balance around the gasification system.

The data from these measurements were used to calculate mean feed concentrations and tolerance limits for the three trace elements. The mean concentrations of arsenic, mercury and lead in the feed coke were found to be 7.61 µg/g, 0.0437 µg/g and 3.50 µg/g, respectively. The 95% tolerance limits were calculated to be 4.39 to 10.83 µg/g for arsenic, 0.0118 to 0.0646 µg/g for mercury, and 1.06 to 5.94 µg/g for lead. These limits provide criteria for assessing sample contamination. A sample exhibiting a concentration above the upper tolerance limit can safely be rejected as contaminated, while a concentration below the lower tolerance limit would indicate a quantitative loss of the element during sample preparation.

Trace Element Mass Balances and Enrichment Ratios

For each gasification run, the mass flow rates of each element in each process stream were calculated and used to obtain mass balances. Percentage recoveries of each element were calculated as:

$$\% = \frac{\text{mass recovered in spent char, cyclone dust, and make gas}}{\text{mass fed in coal}} \times 100$$

Table 5 summarizes the elemental recoveries achieved in gasification runs. In the first two runs listed (44 and 45), no product gas trace element sampling was performed. In the next four, arsenic and lead were recovered from the make gas, and in Run 58 all three elements were recovered.

The mass balance closures and data reproducibility shown in Table 5 are fair, at best. A good deal of the problem may be the uncertainties in the feed concentrations of the elements, which were more than large enough to account for both the scatter and the low measured recoveries. In future runs, multiple sampling from each feed drum will be routinely performed, and steps will be taken to ensure homogeneity of the feed throughout the duration of the run.

Despite the scatter in the data, the measured recoveries show clear patterns of behavior. Arsenic is the least volatile of the three elements. Recoveries of this element were greater than 80%, apparently regardless of temperature, pressure, and steam-to-carbon ratio in the ranges studied. (A more extensive set of tests combined with analysis of variance would of course be required to put this conclusion on a firm basis.) Most of the arsenic is recovered in the spent char (non-volatilized) and cyclone dust (non-volatilized, or volatilized and recondensed.) Only a negligible amount is volatilized and remains volatile long enough to pass out with the make gas.

TABLE 5
SUMMARY OF TRACE ELEMENT MASS BALANCES

Run	P(kPa)	T(°F)*	S/C***	Element	%Recovery Char	 Cyclone Dust	 Gas	 Total
GO-44	802	1700	1.3	As	70	10	**	80
				Pb	70	14	**	84
				Hg	--	--	--	--
GO-45	812	1697	0.8	As	69	8	**	77
				Pb	84	10	**	94
				Hg	72	2	**	74
GO-49	642	1818	0.8	As	64	16	0.08	80
				Pb	53	13	0.31	72
				Hg	51	7	**	50
GO-51	640	1815	0.8	As	85	16	0.002	101
				Pb	53	13	0.31	66
				Hg	51	7	**	58
GO-53	820	1819	1.0	As	78	13	0.002	91
				Pb	54	14	0.80	68
				Hg	46	8	**	54
GO-56	818	1825	1.6	As	82	18	0.003	100
				Pb	53	31	0.44	84
				Hg	37	4	**	41
GO-58	809	1814	1.1	As	70	9	0.002	79
				Pb	55	12	0.24	67
				Hg	27	4	55	85

*Average bed temperature
**Sample train was not operative
***Molar steam to carbon ratio in feed

Of the remaining two elements, lead is the next most volatile. Lead recoveries are generally lower at the higher temperature, but do not appear to be affected by pressure or steam-to-carbon feed ratio. A small but not insignificant fraction of the lead is recovered in the product gas. Calculated concentrations fell in the range 3-13 μg Pb/m^3 gas. The low total recoveries of lead can easily be accounted for in terms of the uncertainty in the feed concentration of this element: for example, employing the upper and lower tolerance limits results in lead recoveries in Run 58 that range from 42.7% to 239.1%.

The fate of mercury in the gasification system is significantly different from that of arsenic and lead. In the absence of the gold amalgamation column, mercury recoveries were as low as 30% and no higher than 60% at the higher temperature. In the one run in which the gold column was used, the concentration of mercury in the dry product gas was 14.8 $\mu g/m^3$, representing 55% of the mercury fed to the reactor, and the total recovery was 85%. Although only this initial result is currently available, it appears that the gold amalgamation system can be effectively used to close the mercury material balance. A second gold column in series with the first will be used to reinforce this conclusion.

In addition to percent recoveries, enrichment ratios were calculated for each element in each stream. The enrichment ratio for each trace element i in each outlet stream j is:

$$E_{ij} = \frac{n_{ij}/n_{aj}}{n_{if}/n_{af}} \qquad (6)$$

where

E_{ij} = enrichment ratio of element i in stream j

n_{ij}, n_{if} = mass flow rates of element i in stream j and feed coal, respectively

n_{aj}, n_{af} = mass flow rates of ash in stream j and feed coal, respectively

An enrichment ratio less than one for an element in a stream indicates that the element is depleted in that stream relative to ash. Other definitions of enrichment ratio have been used, one of which uses the sum of all effluent streams rather than the feed coal as a reference (Kaakinen et al.,1975). However, if a nonvolatile reference substance is chosen, both ratios yield identical results with a perfect mass balance closure.

Trace element enrichment ratios of the spent char and cyclone dust for runs 44 through 58 are presented in Table 6. Significant depletion of all three trace elements is exhibited by the spent char and cyclone dust. Of the three trace elements, mercury is again seen to be consistently the most volatile, followed by lead and arsenic. The extremely low enrichment ratios observed for the cyclone dust may reflect relatively high rates of volatilization from the fine dust particles owing to their large surface to volume ratio.

Comparison with Results of Other Studies

The finding that arsenic is the least volatile of the three trace elements and is essentially completely removed in the condensed effluents is in agreement with results of Forney et al. (1975), Bennett (1977), Page (1977), and Gasior et al. (1978) and the predictions of Loran and O'Hara (1977) and Anderson et al. (1979). Lead displays behavior similar to that of arsenic; however, lead is more volatile and is removed to a lesser extent in the condensed effluents. This result is consistent with those of Forney et al. (1975), Page (1977), and Gasior et al. (1978), and the predictions of Anderson et al. (1979), but contradicts the predictions of Loran and O'Hara (1977). The fact that mercury was found to be the most volatile of the three trace elements conforms with predictions of all of the studies cited above. The relative volatilities exhibited by the three trace elements in this study were also in good agreement with the coal pyrolysis results of Agreda (1979), who showed that arsenic exhibited moderate devolatilization losses, while mercury and lead exhibited significant devolatilization.

TABLE 6
ENRICHMENT RATIOS FOR SPENT CHAR AND CYCLONE DUST
Runs GO-44 through GO-58

Run No.	Element	Char	Cyclone Dust
GO-44	As	1.01	0.09
	Pb	1.02	0.12
	Hg	----	----
GO-45	As	0.85	0.07
	Pb	1.03	0.10
	Hg	0.88	0.02
GO-49	As	0.37	0.22
	Pb	0.30	0.28
	Hg	0.25	0.11
GO-51	As	0.94	0.18
	Pb	0.59	0.14
	Hg	0.57	0.08
GO-53	As	0.89	0.20
	Pb	0.63	0.21
	Hg	0.54	0.13
GO-56	As	1.12	0.33
	Pb	0.72	0.55
	Hg	0.51	0.06
GO-58	As	0.66	0.13
	Pb	0.52	0.18
	Hg	0.25	0.06

WASTEWATER ANALYSIS

The wastewater for the runs reported on here is water from the PCS tank or from the sample train condenser trap. Both the PCS tank and the sample train location are shown on Figure 1.

The PCS tank contains all of the water collected downstream from the venturi scrubber for the entire duration of a run. For the runs shown in Table 7, approximately 160 gallons of fresh tap water were placed in the tank before the run. The venturi scrubber was operated in a recirculating mode at a rate of about twenty gallons per hour with water recirculating from the PCS tank. Samples were taken at the end of the run, and thus contain both the initial fresh water charge and the water condensed from the gasifier make gas, and represent both startup and steady state operation.

TABLE 7
WASTEWATER ANALYSIS

All units are in mg/l except pH

	PCS TANK		TRAP WATER	
	GO-15	GO-56	GO-16	GO-56
Ammonia	78.5	306.3		918.4
Carbon	256	436		2182
Chloride	17.5	13.0	41.9	23.3
COD	557	494		3370
Cyanate	10	398		1033
Cyanide	1.2			
Fluoride			48.4	
Nitrogen	80.7	311		654
pH	5.67	6.09	6.25	6.86
Phenolics	0.3			
Residue	0.24	114		1480
Sulfate	51.4	36.2	7.6	67.3
Sulfide	50.8			
Sulfite	17.6	18.5	5.7	121.4
Sulfur	228	54.0		59.4
Thiocyanate	2.25			
TOC		114		700
TVC	212	334		515

The total time of operation for run GO-15 was 6 hours, and for GO-56 was 10 hours.

A schematic drawing of the sample train was shown in Figure 16 earlier in this chapter. The water collected at the sample train is from the steady state portion of a run only, is collected over a relatively short period of time, and contains only the water condensed from the gasifier make gas. For both the PCS tank water and the sample train water, no appreciable organic matter was detected during the gasification of char.

DATA REDUCTION COMPUTER PROGRAM

The program takes as input the reactor temperature profile and pressure, bed dimensions, solid feed properties (sieve analysis, density, settled bed density, proximate and ultimate analyses), feed rates of coal, steam, oxygen and nitrogen, removal rate of char, reactor leak rate, gas flow rate at the PCS system outlet, masses of coal fed, spent char collected, cyclone dust collected, ultimate analyses of the spent char and cyclone dust, chromatographic analyses of the gases exiting the cyclone and the PCS system, pressure drop across a 20-inch segment of the bed, various feed and effluent flow meter calibration temperatures and pressures, and results of trace element and wastewater constituent analyses.

The output of the program contains the following components:

1. Reactor specifications, including the average bed temperature and pressure, the apparent bed density and void fraction, and the bed expansion factor.
2. Solid feed properties, including coal type, solid particle and settled bed densities, as-received moisture content, average feed particle diameter, and proximate and ultimate analyses.
3. Feed rates of coal, steam, oxygen, and nitrogen, selected feed ratios and inlet conditions, superficial gas velocity, solids holdup, and space times for both gases and solids.
4. The make gas flow rate and chemical composition.
5. Production rates of fuel components and the heating value of the make gas.
6. Carbon, steam, and sulfur conversions.
7. Material balances on total mass, and on carbon, hydrogen, oxygen, nitrogen, and sulfur.
8. An energy balance.
9. Results of water analyses.
10. Results of trace element analyses and trace element material balances.

A program documentation, summary of calculations, and a representative output are given in Appendix B, and a complete source code listing is given in Appendix C.

GASIFIER MODEL

To aid in the analysis of the char gasification runs, a mathematical model of the fluidized bed gasifier was developed. The model takes as input the average reactor bed temperature and pressure, bed dimensions, feed rates of coal, steam, oxygen, nitrogen, and purge nitrogen, solids holdup, ultimate analysis of the feed coke and spent char, and values of three adjustable model parameters, the relative reactivity of the coke, the CO/CO_2 distribution coefficient, and the water gas shift reactivity parameter.

MODEL DEVELOPMENT AND ASSUMPTIONS

The model treats the gasifier as a single perfect mixer, with the following six reactions taking place:

$$C + H_2O = CO + H_2 \tag{7}$$

$$C + 2H_2 = CH_4 \tag{8}$$

$$2C + H_2 + H_2O = CO + CH_4 \tag{9}$$

$$CO + H_2O = CO_2 + H_2 \tag{10}$$

$$C + 1/2O_2 = CO \tag{11}$$

$$C + O_2 = CO_2 \tag{12}$$

Reactions 11 and 12 are the oxidation steps required to supply heat for the remaining reactions. These two reactions are assumed to occur instantaneously in a zone of negligible volume separate from the gasification zone. All oxygen in the feed gas is assumed to be consumed to form CO and CO_2 according to the relation

$$C + aO_2 = (2-2a)CO + (2a-1)CO_2 \tag{13}$$

where a, the combustion product distribution parameter, is an adjustable parameter. A value of $a = 0.5$ indicates that all CO is formed, while a value of $a = 1.0$ indicates that only CO_2 is formed.

Reactions 7, 8, and 9 are the reactions by which Johnson (1974) at the Institute of Gas Technology correlated gasification kinetics. Reaction 7 is the conventional steam-carbon reaction. Reaction 9 is assumed to be an independent reaction, although it is attainable as a linear combination of 7 and 8.

The correlation used by Johnson to describe the carbon conversion is given by

$$r = f_L k_T (1-f_c)^{2/3} \exp(-b f_c^{\,2}) \qquad (14)$$

where r is the rate at which the carbon is gasified, k_T is the sum of the rate constants for reactions 7, 8, and 9, f_c is the fractional carbon conversion and b is a kinetic parameter which depends on gas composition and pressure. Expressions for the rate constants and b are given below.

$$k_I = \frac{\exp\,(9.0201 - 31{,}705/T)\left[1 - \dfrac{P_{CO}\,P_{H2}}{P_{H_2O}\,K_I^E}\right]}{\left\{1 + \exp(-22.2160 + 44{,}787/T)\left[\dfrac{1}{P_{H_2O}} + 16.35\,\dfrac{P_{H2}}{P_{H_2O}} + 43.5\,\dfrac{P_{CO}}{P_{H_2O}}\right]\right\}^2} \qquad (15)$$

$$k_{II} = \frac{P_{H_2}^2 \quad \exp(2.6741 - 33{,}076/T \left[1 - \dfrac{P_{CH_4}}{P_{H2}^2\,K_{II}^E}\right]}{1 + P_{H_2}\,\exp\,(-10.4520 + 19{,}976/T)} \qquad (16)$$

$$k_{III} = \frac{P_{H_2}^{1/2}\,P_{H_2O}\ \exp\,(12.4463 - 44{,}544/T)\left[1 - \dfrac{P_{CH4}\,P_{CO}}{P_{H_2}P_{H_2O}\,K_{III}^E}\right]}{\left[1 + \exp(-6.6696 + 15{,}198/T)\left(P_{H_2}^{1/2} + 0.85\,P_{CO} + 18.62\,\dfrac{P_{CH_4}}{P_{H2}}\right)\right]^2} \qquad (17)$$

$$b = \frac{52.7\,P_{H2}}{1 + 54.3\,P_{H2}} + \frac{0.521\,P_{H_2}^{1/2}\,P_{H_2O}}{1 + 0.707\,P_{H2} + 0.50\,P_{H2}^{\ 1/2}P_{H_2O}} \qquad (18)$$

where

P_i = partial pressure of component i, atm

T = bed temperature, degrees Rankine

K^E_I, K^E_{II}, K^E_{III} = equilibrium constants

The relative reactivity factor f_L is determined from

$$f_L = f_0 \exp(8467/T_o) \tag{19}$$

where T_o is the maximum temperature to which the char has been exposed prior to gasification. The relative reactivity factor, f_0, which is an adjustable parameter whose values depend on the particular char used, has values ranging from 0.3 for low-volatile bituminous coal chars to about 10 for North Dakota lignites (Johnson, 1974).

Reaction 15 is the water gas shift reaction, often assumed to be at equilibrium in gasification processes. Results described earlier indicate this may be a bad assumption, leading to the necessity of incorporating shift kinetics into the model. The rate expression used is that given by Wen and Tseng (1979)

$$r_4 = 1.6652\times10^4 V(1-e) f_{wg} \exp(-25147/T) PG \tag{20}$$

where

V = bed volume (cm^3)

G = $y_{CO} - y_{H2}\, y_{CO2} / (y_{H2O} K^E_{IV})$

e = bed void fraction

f_{wg} = adjustable shift reactivity parameter (varies from char to char)

K^E_{IV} = equilibrium constant

P = reactor pressure

The equilibrium constants for the water gas shift reaction and for reactions 7, 8, and 9 were taken from Lowry (1963), and were fit to the equation

$$\ln K^E = a_0 / T + a_1 \tag{21}$$

by least-squares analysis (Alexander, 1978). The results are given in Table 8.

TABLE 8
EMPIRICAL CONSTANTS OBTAINED FROM LEAST-SQUARES FIT OF EQUILIBRIA DATA

Reaction	a_0	a_1
$C + H_2O \rightleftharpoons CO + H_2$	-2901.6	17.09
$C + 2H_2 \rightleftharpoons CH_4$	17744.4	-12.23
$2C + H_2 + H_2O \rightleftharpoons CO + CH_4$	-11266.2	4.86
$CO + H_2O \rightleftharpoons CO_2 + H_2$	8395.2	-4.29

REACTOR SIMULATION

The model program first takes the input data and converts the input values to appropriate units. The component flow rates out of the combustion zone are calculated as

$$q_{O2} = q_{H2} = q_{CH4} = q_{H2S} = q_{COS} = 0 \quad (22)$$

$$q_{CO} = ((2-2a)/a)q^0_{O2} \quad (23)$$

$$q_{CO2} = ((2a-1)/a)q^0_{O2} \quad (24)$$

$$q_C = q_C - q^0_{O2}/a \quad (25)$$

$$q_{H2O} = q^0_{H2O} \quad (26)$$

$$q_{N2} = q^0_{N2} \quad (27)$$

where q_i = molar flow rate of component i, and q^0_i = molar flow rate of component i into the combustion zone. (purge nitrogen is not included in the nitrogen flow rate). The carbon conversion due to combustion is calculated by

$$f_{comb} = 1 - q_c/q^0_c \quad (28)$$

An initial carbon conversion of twenty percent (based on the carbon flow out of the combustion zone) is made, with the assumption that all carbon conversion occurs by the reaction

$$C + H_2O \rightleftharpoons CO + H_2 \quad (29)$$

An initial CH_4 flow estimate is made by assuming it to be one percent of the combined molar flows of CO, CO_2, H_2, and H_2O. The initial estimates of molar product flow rates, q'_i, are calculated as

$$q'_{O2} = q'_{H2S} = q'_{COS} = 0 \tag{30}$$

$$q'_{CO} = q_{CO} + 0.20q_C \tag{31}$$

$$q'_{CO2} = q_{CO2} \tag{32}$$

$$q'_C = 0.80q_C \tag{33}$$

$$q'_{H2O} = q_{H2O} - 0.20q_C \tag{34}$$

$$q'_{N2} = q_{N2} \tag{35}$$

$$q'_{CH4} = 0.01(q_{CO}+q_{H2}+q_{CO2}+q_{H2O}) \tag{36}$$

$$q'_{H2} = 0.20q_C \tag{37}$$

The estimated product flows are then used in the previously described rate expressions to calculate reaction rates for reactions 7-10. These calculated rates are then compared to the rates calculated in the previous iteration. For the first iteration, the calculated rates are compared to the following arbitrarily set rates

$$r^o_1 = 0.0100 \text{ fraction C consumed/min} \tag{38}$$

$$r^o_2 = -0.0005 \text{ fraction C consumed/min} \tag{39}$$

$$r^o_3 = 0.0025 \text{ fraction C consumed/min} \tag{40}$$

$$r^o_4 = 0.0020 \text{ lb moles/min} \tag{41}$$

Convergence is then checked. The convergence criteria require that all four reaction rates show percent differences for successive iterations of less than 0.1%. If convergence is not achieved, new rate values must be determined.

Following the calculation of $\{r_i^1\}$, new rates are calculated by modified successive substitution with convergence accelerated by the Dominant Eigenvalue Method (Orbach and Crowe, 1971). For each iteration, the dominant eigenvalue E of the vector of reaction rates is calculated:

$$E^k = \left\| \frac{\Delta r^{k-1}}{\Delta r^{k-2}} \right\| = \frac{\{\Sigma(r_i^k - r_i^{k-1})^2\}^{0.5}}{\{\Sigma(r_i^{k-1} - r_i^{k-2})^2\}^{0.5}} \tag{42}$$

where the superscripts indicate the iteration number. Eigenvalue stability is considered to have been achieved when both of the following conditions are satisfied:

$$\text{(a)} \quad \left| (E^k - E^{k-1})/E^k \right| \leq 0.01 \tag{43}$$

$$\text{(b)} \quad n \geq 5 \tag{44}$$

where n is the number of iterations since eigenvalue stability was last achieved. When this condition is met, new rates are calculated as

$$r_i^{k+1} = r_i^{k-1} + p[(r_i^k - r_i^{k-1})/(1-E^k)] \tag{45}$$

where p is a damping factor.

When eigenvalue stability is not achieved (i.e., when eqs. (43) and (44) are not satisfied), new rates are calculated by modified successive substitution:

$$r_i^{k+1} = qr_{i,c}^k + (1-q)r_{i,e}^k \tag{46}$$

where $r_{i,c}^k$ is a rate calculated in the kth iteration from the kinetic rat equations, $r_{i,e}^k$ is an estimated rate for the kth iteration, and q is second damping factor. Preliminary studies showed that damping factor values p=0.7 and q=0.3 provide rapid and stable convergence; these values were therefore incorporated into the model program.

The new rates are used to calculate new product flow rates for the principal gas components:

$$q_{CO} = q_{CO}' + M_c(r_1+0.5r_3) - r_4 \tag{47}$$

$$q_{CO2} = q_{CO2}' + r_4 \tag{48}$$

$$q_{H2} = M_c(r_1-2r_2-0.5r_3) + r_4 \tag{49}$$

$$q_{H2O} = q_{H2O}' + M_c(-r_1-0.5r_3) - r_4 \tag{50}$$

$$q_{CH4} = M_c(r_2+0.5r_3) \tag{51}$$

where M_c is the molar holdup of carbon in the fluidized bed and q_i' is the flow rate of component i leaving the first stage. The flow rate of H_2S is estimated by assuming that the sulfur conversion equals the carbon conversion, and all converted sulfur forms H_2S. There is currently no provision for estimating COS formation other than equilibrium by Equation 5 on page 25.

The newly determined product rates are then used in the kinetic rate expressions to calculate reaction rates, and convergence is again checked. This procedure is continued until the convergence criteria are satisfied.

The newly determined product rates are then used in the kinetic rate expressions to calculate reaction rates, and convergence is again checked. This procedure is continued until the convergence criteria are satisfied.

The carbon conversion due to the gasification reactions, f_{gas}, is based on the flow of carbon out of the combustion zone. It is converted to an initial feed basis,

$$f_{gas} = f_{gas}(1 - f_{comb}) \tag{52}$$

and the total carbon conversion is calculated.

$$f_c = f_{comb} + f_{gas} \tag{53}$$

The steam conversion is also calculated:

$$f_{H2O} = (1 - q_{H2O})/q_{H2O} \tag{54}$$

The nitrogen flow rate is adjusted for the addition of purge nitrogen, which is assumed to combine with the product gas after the product gas leaves the fluidized bed:

$$q_{N2} = q_{N2} + q_{purge} \tag{55}$$

From the final product gas flow rates, the total molar flow rate

$$Q = \Sigma q_i \tag{56}$$

$$i = CO, CO_2, CH_4, H_2, N_2, H_2S, COS, H_2O$$

the mole fractions in the product gas

$$y_i = q_i/Q \tag{57}$$

and the dry product gas rate in SCFM

$$SCFM = Q(1-y_{H2O})(359\ SCF/lbmole) \tag{58}$$

are evaluated. The predicted char removal rate is calculated as

$$Q_{CH} = q^0_C(1-f_C)/z_C \tag{59}$$

where z_C is the weight fraction of carbon in the spent char. The predicted ash content of the spent char is calculated from

$$z_{ash} = x_{ash}/[x_{ash}+(1-x_{ash})(1-f_c)] \tag{60}$$

where x_{ash} is the weight fraction of ash in the feed.

The model output prints reactor conditions, feed rates, coal feed analysis, model parameters, and comparisons between predicted and measured values of carbon and steam conversion, dry make gas flow rate, spent char removal rate and ash content, and mole percents of the wet product gas components. Outputs for all runs are given in Appendix A.

EVALUATION OF MODEL PARAMETERS

In its present form, the model has three adjustable parameters:

1. the char reactivity, f_o
2. the combustion product distribution parameter, a, which specifies the split between CO and CO_2 in the products of the combustion stage of the gasification
3. the water gas shift reactivity parameter, f_{wg} .

These parameters were evaluated by using a Pattern Search algorithm to minimize a function of the sum of squared deviations between predicted and measured values of gasifier performance variables. The function is

$$Y = \Sigma \left[W_i \left(\frac{\phi_p - \phi_m}{\phi_m}\right) + W_2 \left(\frac{f_p - f_m}{\phi_m}\right)^2 + W_3 \left[\left(\frac{y_{H2,p} - y_{H2,m}}{y_{H2,m}}\right)^2 + \left(\frac{y_{CO,p} - y_{CO,m}}{y_{CO,m}}\right)^2 + \left(\frac{y_{CO2,p} - y_{CO2,m}}{y_{CO2,m}}\right)^2 \right] \right] \qquad (61)$$

where W_1, W_2, and W_3 are arbitrarily set weighting factors, ϕ is the dry make gas flow rate, f is the total carbon conversion, y_i is the mole fraction of gas i in the product gas, and the subscripts p and m indicate predicted and measured values. Nine runs were chosen to be included in the function evaluation. These nine runs (GO 26-28, and 44B-49) include those runs which have had the best mass balance closures of all runs carried out to date.

The values of f_o and a were first determined by setting $W_1 = 1$, $W_2 = 1$, and $W_3 = 0$. This weighting scheme was chosen since the predicted make gas flow rate and carbon conversion are highly sensitive to the values of f_o and a, and relatively insensitive to the value of f_{wg}. This resulted in values of

$$f_o = 0.50 \tag{62}$$
$$a = 0.95 \tag{63}$$

Holding f_o and a constant at the above values, Eq. (61) was again minimized, with $W_1 = W_2 = 0$ and $W_3 = 1$, in order to determine the optimal value of f_{wg}. This weighting scheme was used as f_{wg} has a large influence on the predicted product gas composition, but only a small effect on the predicted carbon conversion and make gas flow rate. This gave a result of

$$f_{wg} = 9.9 \times 10^{-6} \tag{64}$$

The value of a, when substituted into Eq. 13, indicates that 90% of the carbon oxidized forms CO_2 and 10% forms CO. An equation by Arthur (1951) predicts values of 0.57 at 1400 F to 0.52 at 2000 F, while several gasification studies have assumed a = 1.0.(Caram et al., 1979; Institute of Gas Technology, 1978; Pukanic et al., 1978; Sundaresan and Amundson, 1979)

Johnson (1975) developed a correlation for char reactivity

$$f_o = 6.2\, y\, (1-y) \tag{65}$$

where y is the dry, ash free carbon fraction in the original raw coal. Eq. 12 predicts a value of $f_o = 1.1$, which is larger than that determined in this study. The difference may be due to the differences in the microbalance used by Johnson and the fluidized bed of this study.

The value of $f_{wg} = 9.9 \times 10^{-6}$ indicates that the shift reaction rate is approximately five orders of magnitude less than the rate obtained in catalytic shift reactors. Wen and Tseng (1979) used a shift reactivity value of 1.7×10^{-4} in modeling the gasification of a bituminous coal by the SYNTHANE process. The larger value used by Wen and Tseng may be attributed to the differences between the coal of their study and the char used in this study.

ACID GAS REMOVAL SYSTEM

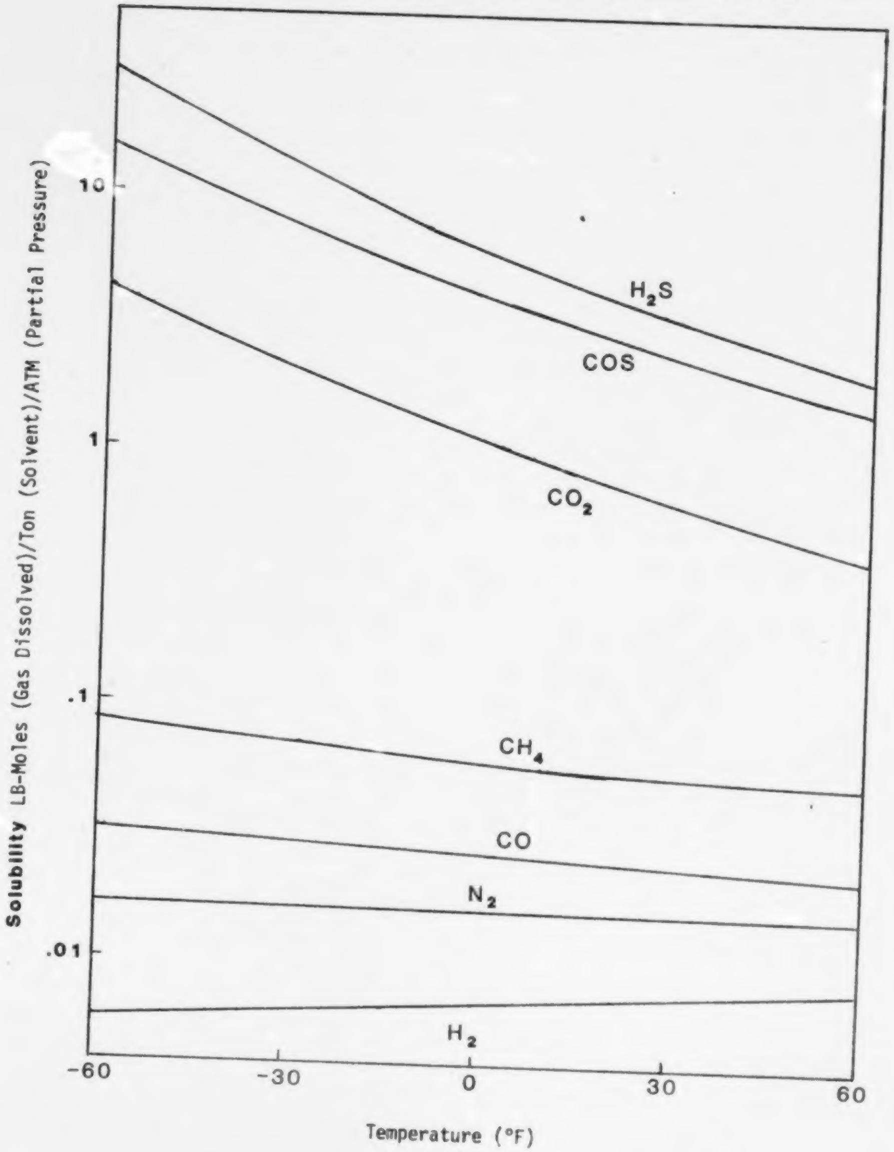
Acid gas removal systems have been used extensively in the petroleum and natural gas industries to remove carbon dioxide and sulfur gases, primarily hydrogen sulfide, from product streams. The general objective of these systems is to remove diluents that reduce the heating value of the product gas and/or compounds that would be unacceptable if released to the atmosphere or fed to catalytic conversion processes. Although numerous processes and solvents have been developed to meet these objectives, few are considered suited to the new challenges associated with cleaning gases produced by coal gasification (Ghassemi et al, 1979).

The primary difficulty associated with processing gases from coal is that they contain significantly greater amounts of carbon dioxide and a more complex array of sulfur, hydrocarbon and nitrogen compounds than do natural gases. This latter group of constituents alters behavior of solvents, raises the possibility of product gas contamination, and complicates recovery of sulfur compounds by conventional conversion operations. The range of functional groups found in gases produced by coal gasification is extensive; the range of volatilities is also broad, causing potential problems with solvent regeneration. Although several alternative acid gas removal systems exist, physical solvent systems are usually chosen in the cleaning of coal gasification product gas. Of the collection of physical solvents and processes available, systems using refrigerated methanol have been used most frequently in coal gasification applications. The SASOL facilities in South Africa and the Kosovo operations in Yugoslavia are examples in which methanol has been used in acid gas removal systems coupled with commercial coal gasification units. Despite the experience with the large scale operations mentioned above, there has been little work reported in the open literature which characterizes fates of many of the sulfur, nitrogen and hydrocarbons handled by the processes.

Figure 18 shows solubilities of various gases in methanol as a function of temperature (Ranke, 1972). The data presented show the solubility of each gas at a partial pressure of one atmosphere; nonidealities associated with gas or liquid mixtures are not reflected in this figure. Ferrell et al (1980) have developed a thermodynamic framework to consider these nonidealities. Despite the conditions under which data is used to construct Figure 18 were taken, relative solubilities of the individual components should be representative of actual behavior.

Figure 18

SOLUBILITY OF GASES IN METHANOL (Ranke, 1972)



ACID GAS REMOVAL PROCESS

Figure 19 shows a process flow sheet for the acid gas removal system (AGRS) used in this study. It was designed so that any of four different solvents could be used:

1. refrigerated methanol

2. hot potassium carbonate

3. monoethanolamine

4. dimethyl ether of polyethylene glycol(DMPEG)

With minor modifications, other solvents could also be used. Feed gas from either the gasifier or from a mixing manifold can be used in making process measurements.

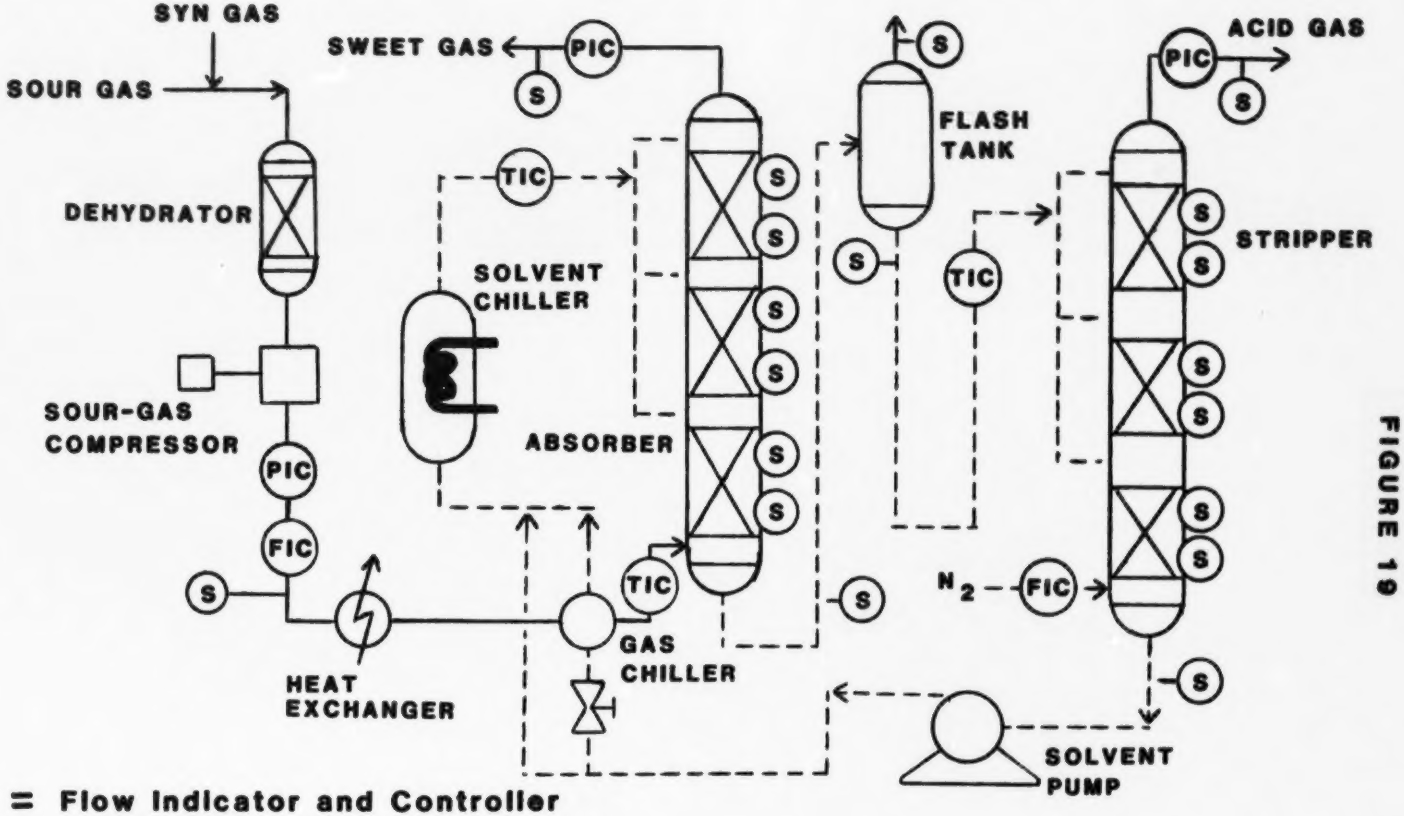
The AGRS consists of an absorber-flash tank-stripper combination with the necessary auxilliary equipment. The flash tank can be operated at pressures ranging from atmospheric to 28 atmospheres absolute. Operating pressure determines the quantity and composition of the flashed gas. The absorber and stripper are both packed columns, each containing three sections of packing, any or all of which can be used in mass transfer studies. Both are insulated and approach adiabatic operation. Operating ranges and column characteristics are given in Table 9 for refrigerated methanol as the acid gas removal solvent.

TABLE 9
COLUMN SPECIFICATIONS AND OPERATING RANGES FOR REFRIGERATED METHANOL

	Absorber	Stripper
Total Packed Height	21 ft.	21 ft.
Column Diameter	5 inches	6 inches
No. of Packed Sections	3	3
Packing Type	Ceramic Intalox Saddles	Ceramic Intalox Saddles
Packing Size	1/4 inch	1/4 inch
Operating Temperature	-35 F to -10 F	-10 F to 60 F
Operating Pressure	100-500 psig	10-25 psig
Liquid Flow Rate	0.5-1.5 gpm	0.5-1.5 gpm
Gas Flow Rate	10-20 scfm	2-10 scfm

FIGURE 19

Acid Gas Removal System (AGRS)


SYN GAS
SOUR GAS
DEHYDRATOR
SOUR-GAS COMPRESSOR
PIC
FIC
S
HEAT EXCHANGER
SWEET GAS
PIC
S
TIC
SOLVENT CHILLER
ABSORBER
S
S
S
S
S
S
TIC
GAS CHILLER
S
S
FLASH TANK
S
TIC
ACID GAS
PIC
S
STRIPPER
S
S
S
S
S
S
N_2
FIC
S
SOLVENT PUMP

FIC = Flow Indicator and Controller
PIC = Pressure Indicator and Controller
TIC = Temperature Indicator and Controller
S = Sample Port

A refrigeration system provides sufficient cooling to feed methanol to the absorber at temperatures as low as 236 K (-35 F). Inert gas (nitrogen) is used to strip the methanol of acid gases but a reboiler is available for thermally stripping (regenerating) the chemical solvent systems.

SAMPLING AND ANALYSIS

As shown in Figure 19, samples can be taken for analysis from several locations in the acid gas removal system. Gas samples are taken at operating pressures using 1-liter stainless steel bombs and at lower pressures using 1-liter glass bombs. The glass bombs are coated internally with hexamethyldisilizane to reduce the adsorption of sulfur, nitrogen and hydrocarbon compounds.

Gas chromatography was commonly used for analysis of gas samples taken from the acid gas removal system. Permanent gases, including carbon monoxide, carbon dioxide, nitrogen, hydrogen and methane were determined using a thermal conductivity detector. Sulfur compounds, such as hydrogen sulfide, carbonyl sulfide, mercaptans, organic sulfides, carbon disolfide and thiophene, were determined using a flame photometric detector. Hydrocarbons were determined using a flame ionization detector.

Liquid samples can be taken at the absorber, flash tank and stripper exits at the prevailing pressures. Attempts to withdraw either liquid or vapor samples from the packed columns have been unsuccessful.

In recent runs, liquid samples have been taken at several points in the system to determine if accumulation of chemical substances is significant. These samples are analyzed off-site using gas chromatography/mass spectrometry. Future plans call for additional analysis with high pressure liquid chromatography.

Attaining steady state operation was required for the samples to have meaning. Run times were generally of the order of 10 hours, with the last 2-3 hours being at steady state, as indicated by constant temperatures, pressures and flow rates. In some runs, consecutive samples were taken of the gas streams to insure that their compositions were constant; this served to confirm the definitions of steady state used in this work.

RESULTS USING DEVOLATILIZED COAL

Preliminary to the study involving the cleaning of gas from the gasification of a non-pretreated coal, several runs were made heating the gas produced during char gasification. These runs were to serve as a basis of comparison for later runs made with coal. The AGRS runs and the corresponding gasifier run are listed below:

Gasifier	AGRS
GO-56	AM-30
GO-57	AM-35
GO-60	AM-36
GO-61	AM-37

Complete listings of the data taken from these runs are listed in Appendix A. Discussion of these runs are included here.

Mass Balances

One of the objectives in each of the initial runs was to achieve a closed material balance around the pilot plant. This required the ability to operate the plant at a steady state for long periods of time. Also, accurate flow measurements and chemical analyses are necessary as are proper sampling techniques.

A considerable amount of time was spent in improving mass balance closure so that deviations of less than 10% resulted. Because all flow streams were measured by orifice flow meters and laminar flow elements, calibrations had to correct for the effect of chemical composition on flow stream properties. To account for differences between the gas used for calibration and the process gas, a density correction was provided for orifice meter calibrations and a viscosity correction was provided for laminar flow element calibrations. These corrections were made to the flow rate measurements recorded by the data acquisition system and reported in run summaries.

In cases where more than 10% deviation from mass balance closure was measured, flow meter and chemical analysis problems can be cited. Because of analytical difficulties, gas samples were not analyzed for methanol in these runs. Failure to account for methanol losses in the gas exiting the flash tank and in the acid gas stream is probably a factor in mass balance overestimation.

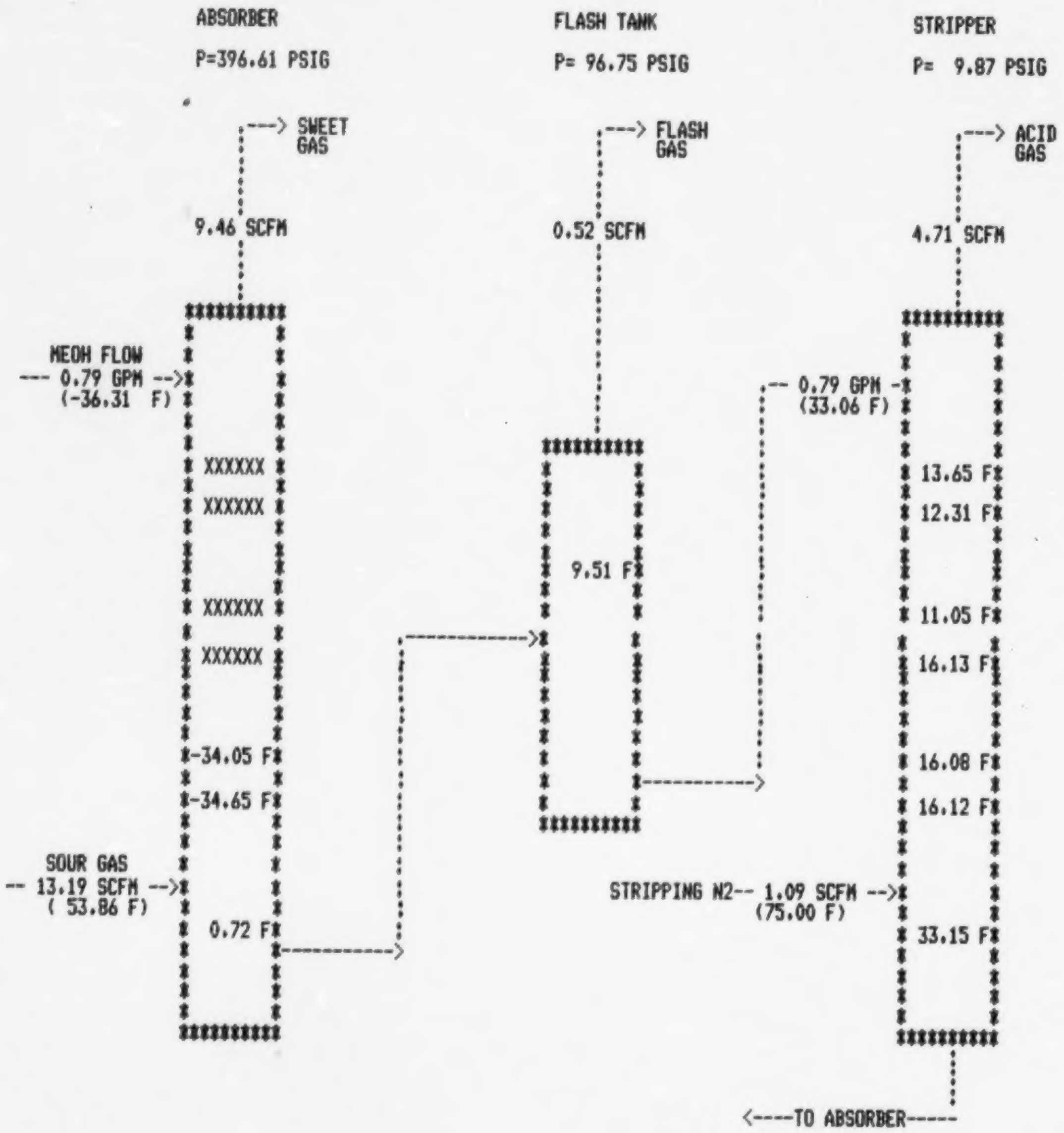
The reported compositions of liquids exiting each vessel were calculated by difference. In early runs on the system, liquid samples between columns and at the stripper exit were taken as were samples from the column packing. Sampling and analytical problems led to the temporary abandonment of this practice. The liquid exiting the stripper, however, is usually sampled and analyzed for residual acid gases.

Overall system performance can be discussed using Run AM-35 as an example. Figure 20 shows the condition at which the system was operated in this run, which was made using 7 feet of packing in the absorption column and 21 feet of packing in the stripper. The mass balance report of AM-35 (Figure 21) shows that the total balance was within 3 percent of complete closure. In earlier runs, there were significant problems with getting closure of a

RUN NUMBER A-M-35
INTEGRATED RUN
DATE 6/26/1980

FIGURE 20

COLUMN TEMPERATURE PROFILES & MASS BALANCES


ABSORBER
P=396.61 PSIG
SWEET GAS
9.46 SCFM
MEOH FLOW
--- 0.79 GPM -->
(-36.31 F)
XXXXXX
XXXXXX
XXXXXX
XXXXXX
-34.05 F
-34.65 F
SOUR GAS
-- 13.19 SCFM -->
(53.86 F)
0.72 F
FLASH TANK
P= 96.75 PSIG
FLASH GAS
0.52 SCFM
9.51 F
STRIPPER
P= 9.87 PSIG
ACID GAS
4.71 SCFM
0.79 GPM
(33.06 F)
13.65 F
12.31 F
11.05 F
16.13 F
16.08 F
16.12 F
STRIPPING N2-- 1.09 SCFM -->
(75.00 F)
33.15 F
<----TO ABSORBER-----

```
*****************************************
*                                       *
* NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
*                                       *
*     ACID   GAS   REMOVAL   SYSTEM     *
*                                       *
*****************************************
```

FIGURE 21

```
          RUN NUMBER A-M-35
           INTEGRATED RUN
          DATE    6/26/1980

                          STREAM COMPOSITION (MOL %)
                          ------ -----------

                                                             *         *          *
          SOUR     SWEET     FLASH     STRIP     ACID     ABSORB     FLASH     STRIP
          GAS      GAS       GAS       N2        GAS      EXIT       EXIT      EXIT

 CO2     28.010    0.950    43.810     0.000    73.170     5.674     5.346     0.000
 H2S      0.807    0.037     0.526     0.000     1.970     0.162     0.159     0.013
 COS      0.045    0.003     0.038     0.000     0.127     0.009     0.009     0.000
 MEOH     0.000    0.000     0.000     0.000     1.200    93.934    94.453    99.973
 H2      33.190   45.500    12.880     0.000     0.000     0.118     0.013     0.014
 CO      20.200   27.850    24.590     0.000     1.660     0.048     0.000     0.000
 N2      15.700   23.230    13.920   100.000    21.120     0.000     0.000     0.000
 CH4      2.010    2.440     4.240     0.000     0.700     0.054     0.020     0.000
 C2H4     0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.000
 C2H6     0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.000

                                    *
                                     CALCULATED


                          MASS BALANCE (LB-MOLES/HR)
                          ---- -------


               IN                       OUT
               --                       ---

                                                                    *         *
          SOUR      STRIP          SWEET     FLASH     ACID         TOTAL     TOTAL     % RECOVERY
          GAS       N2             GAS       GAS       GAS          IN        OUT

 CO2      0.618     0.000          0.015     0.038     0.575        0.618     0.628       101.7
 H2S      0.018     0.000          0.001     0.000     0.015        0.018     0.017        92.9
 COS      0.001     0.000          0.000     0.000     0.001        0.001     0.001       109.4
 MEOH     0.000     0.000          0.000     0.000     0.009        0.000     0.000         0.0
 H2       0.732     0.000          0.719     0.011     0.000        0.732     0.730        99.8
 CO       0.445     0.000          0.440     0.021     0.013        0.445     0.475       106.6
 N2       0.346     0.182          0.367     0.012     0.166        0.528     0.545       103.2
 CH4      0.044     0.000          0.039     0.004     0.006        0.044     0.048       107.7
 C2H4     0.000     0.000          0.000     0.000     0.000        0.000     0.000         0.0
 C2H6     0.000     0.000          0.000     0.000     0.000        0.000     0.000         0.0

 TOTAL    2.205     0.182          1.581     0.087     0.787        2.386     2.444       102.4
 (LB-MOLES/HR)

                               *
                                METHANOL-FREE BASIS

          TOTAL METHANOL LOSS=  0.009 LB-MOLES/HR =  0.045 GALLONS/HR
```

CO_2 balance. However, the problem was traced to flow meter calibrations for the acid gas stream and also to failure to account for the methanol present in this stream. A mass balance of this quality lends credibility to the results obtained, especially those for the sulfur compounds. Methanol analyses of the three exiting gas streams were not performed for this run but, other runs showed negligible amounts in the sweet gas, with the concentration increasing for the flash gas and the acid gas. The increased presence of methanol in these latter streams was expected because they are at decreased pressure and increased temperature.

System Performance

Since the focus of these runs was on absorber performance, variables among the data sets were absorber pressure and flow rate and temperature of the methanol fed to the absorber. Because of other run objectives and the inherent difficulty in reproducing gasifier operation, it was not possible to hold the composition of gas fed to the acid gas removal system constant from one run to the next. This is one of the reasons that substantial modeling efforts have been made for the system, as will be discussed subsequently.

Temperatures throughout the acid gas removal system are keys to understanding the performance of the process. Since the sampling of liquid and gas from the column packing proved to be unsuccessful, column temperature profiles take on added significance in determining mass transfer rates. Current modeling efforts rely on comparisons of measured and predicted column temperature profiles. Because of the large heat effects associated with CO_2 absorption in methanol, this profile is indicative of the rate of CO_2 transfer.

Acid Gas Distribution

Selection of the flash tank pressure was based on several factors. The Rectisol process, which uses methanol as a solvent, contains a series of flashing operations designed to remove the acid gases from the solvent and allow for some separation of the sulfur compounds from CO_2. In the system used in this study, operation at moderate pressures (50-150psig) provided some insight into how these gases distribute. Also, flash tank operation indicates how closely a vapor-liquid equilibrium model in development, and referred to earlier, predicts actual system performance. Finally, trial and error showed that this range of operating pressures is more compatible with overall system performance; i.e., the effect of process controller oscillation on sampling and steady state operation is reduced.

Stripper operating pressure was 10psig for AM-35 and for other runs on the system. In practice, stripper operating conditions are chosen to provide a balance between solvent losses and regeneration: high temperatures and low pressures favor both.

The pressure used in this study was the lowest that the stripper pressure controller could maintain without significant controller oscillation. Inlet temperature to the stripper was not controlled in these runs; however, in later runs with coal a trim heater was installed so that this variable could be adjusted to and maintained at a desired value.

Table 10 shows the ratios of acid gas concentrations for the various gas streams in the AGRS. The ratios of the acid gases exiting the stripper in the concentrated acid gas stream are the same as those in the entering sour gas stream. This is the expected result for non-selective physical solvent systems.

TABLE 10
RATIOS OF ACID GAS CONCENTRATIONS IN PROCESS STREAMS

Run		Sour Gas	Sweet Gas	Flash Gas	Acid Gas
30	CO_2/H_2S	27.0	30.4	68.1	28.1
	H_2S/COS	21.7	16.0	14.7	21.7
	CO_2/COS	585.7	486.7	1004.7	611.1
35	CO_2/H_2S	34.7	25.7	80.7	36.4
	H_2S/COS	17.9	12.3	13.8	15.5
	CO_2/COS	622.4	316.7	1117.1	566.0
36	CO_2/H_2S	23.4	6.2	59.3	31.4
	H_2S/COS	18.6	17.0	15.0	16.7
	CO_2/COS	435.4	105.0	887.6	524.0
37	CO_2/H_2S	29.0	15.6	76.1	31.4
	H_2S/COS	18.4	13.7	14.6	17.4
	CO_2/COS	553.0	213.3	1112.1	546.5

Results shown in Table 10 are indicative of differences in solubility among the acid gases. Comparison of H_2S:COS ratios in the sour gas and sweet gas streams show that H_2S is absorbed with a slightly higher efficiency than COS. This is expected because H_2S has a slightly higher solubility than COS over the temperature range used.

The ratios CO_2:COS and CO_2:H_2S in the flash gas are about twice those found in the entering sour gas stream. This indicates that there is the potential to concentrate CO_2 fed to the system through a flashing process. The selectivity of the flash may be affected by the pressure at which the operation is controlled. Note that the ratio H_2S:COS is again less than that found in the sour gas. This fact may be explained by noting that H_2S is more soluble than COS, which means that proportionately less H_2S will flash upon pressure reduction.

Absorber Column Performance

Table 11 contains the results associated with absorber column performance for four integrated runs treating a gas produced from devolatilized coal. More complete data on these runs is presented in appendix D. An attempt was made to vary system conditions to show the effect on acid gas removal efficiencies. A comparison of the results from these runs underline the importance of mathematical modeling to analyze system performance.

TABLE 11
ABSORBER OPERATION

Run				
Pressure (atm absolute)	28.2	28.2	21.4	31.6
Ht. of packing(ft)	7.1	7.1	7.1	21.3
L in (lb-moles/hr-ft^2)	60.7	72.1	72.6	71.1
G in (lb-moles/hr-ft^2)	16.2	15.9	16.4	16.6
G out(lb-moles/hr-ft^2)	11.5	11.4	12.8	12.1
T_L in (^{o}F)	-34.1	-36.3	-32.4	-36.3
T_L out(^{o}F)	3.5	-0.6	-1.7	7.2
T_G in (^{o}F)	54.0	53.9	57.5	59.9
Liquid Temperature rise(^{o}F)	37.6	35.7	30.7	43.5
H_2S in (ppm)	9096	8072	8918	8631
H_2S out (ppm)	476	371	682	405
% removed	96.3	94.5	94.2	95.8
CO_2 in (%)	24.6	28.0	20.9	25.1
CO_2 out(%)	1.5	1.0	0.4	0.6
% removed	95.8	97.6	98.4	98.1

All runs show an acid gas removal efficiency of at least 94.0% for the range of operating conditions used. Also, only small differences in component removal efficiences can be seen despite the changes in packed height, liquid flow rate, and operating pressure. The reason for this can be explained by examining the inlet gas compositions for each run, and by considering mass transfer limitations and by observing the residual acid gases in the solvent fed to the absorber.

Gasifier operation dictates the composition of the gas stream fed to the AGRS. For the four runs shown here, the inlet gas flow rate to the absorber varied only slightly, but the CO_2 content of the stream varied significantly. This affects the absorber column temperature profile, as the magnitude of the absorption exotherm depends almost entirely on the amount of CO_2 absorbed.

Effects of this exotherm can be seen by comparing the results of Runs AM-35 and AM-36 in Table 11. Although AM-35 was made at a higher absorber pressure and a lower inlet liquid temperature, the acid gas removal efficiencies are approximately the same. However, since there was 7% more CO_2 in the entering gas stream for Run AM-35 than for Run AM-36, the exotherm associated with CO_2 absorption was greater in Run AM-35. The increased solvent temperature resulting from this effect offsets the expected increase in column removal efficiency.

Run AM-37 was made with three times the packed height used in the other runs, but resulted in only small improvements in acid gas removal efficiency. This indicates that for the range of operating conditins used, acid gas removal efficiency is approaching an often noted condition in which large packing heights are required to remove small concentrations of impurities. Further improvements in acid gas removal efficiencies could be obtained with lower inlet temperatures, higher operating pressures or larger liquid flow rates.

The effect of changing liquid flow rates can be seen by comparing Runs AM-30 and AM-35. The increase in the liquid flow rate from 60.7 lb-moles/hr/sq. ft. to 72.1 lb-moles/hr/sq.ft improved CO_2 removal efficiency by 1.8%. H_2S and COS removal remained about the same probably because of mass transfer limitations.

Another important factor to consider in AGRS operation is the amount of residual acid gases that remain in the methanol exiting the stripper. For the runs made here, the inlet temperature to the stripper was not controlled. Although samples of the solvent leaving the stripper were not taken for each of these runs, results obtained later show that significant amounts of H_2S were probably present in all runs. This means that the mass transfer driving force at the top of the absorption column decreases, thereby lowering removal efficiencies; i.e. the concentration of acid gases in the entering sweet gas is strongly affected by stripping column performance.

The influence of stripping column performance on acid gas removal efficiency can be a problem. Since these four runs were made, a heater has been installed in the solvent line to the stripper so that the inlet stripper temperature can now be controlled. This creates another degree of freedom in AGRS operation and has led to better acid gas removal efficiencies. Previously, the temperature of the solvent entering the absorber determined the temperature of the feed solvent to the stripper. With the heater now in line this temperature can be adjusted to balance the effects of solvent losses with stripping efficiency.

The results from these four runs clearly point to the need to develop a mathematical model to assist with the analysis of experimental results and provide a basis for analyzing more complicated process configurations. Although there exists the possibility of feeding synthetic gas streams to the AGRS, the most useful information comes from runs where gasifier product gas is used. Because of the variability associated with gasifier operation, a carefully structured experimental plan would be difficult to complete. The strategy used thus far has been to cover a wide range of operating conditions. Then, a mathematical model will be used to extend these results to process situations that cannot be studied with the pilot plant.

SOLVENT REGENERATION

After approximately 60 hours of operation, analysis of methanol was performed to determine accumulation of various constituents in the system. These analyses showed that there was no apparent buildup of hydrocarbons or other species in the methanol used to condition gas produced from the devolatilized coal. Considering the fact that devolatilized coal was used as a feedstock in these runs, this result should not be surprising. As mentioned, the only detected hydrocarbon species in the feed gas to the acid gas removal system was methane. Very small amounts of ethane and ethylene may be present, but only in trace quantities.

The devolatilized coal used in these runs contained very little volatile matter (less than 2.0%). Accordingly, sulfur gases produced in the reactor are generally the product of the gas phase hydrolysis of H_2S, the predominant sulfur gas form. This means that most of the sulfur gases fed to the acid gas removal system were H_2S and COS, with small amounts of CS_2. Traces of methyl mercaptan, ethyl mercaptan, methyl sulfide and thiophene were also found in some gas streams, but their irregular appearance prevented any quantitative conclusions concerning their distribution. These sulfur species are probably related to the volatile matter present in the feed char.

PROCESS MODELING

At present, mathematical modeling efforts have mainly dealt with describing the operation of the packed absorption column for the adiabatic case. A calculational technique first described by Feintuch and Treybal (1978) for packed column design has been implemented on the computer and is currently used for analyzing runs where synthetic gas mixtures of carbon dioxide and nitrogen are fed to the absorption column. Thus far, only cases for the absorption of a single component have been modeled but a multicomponent case is currently being developed to describe the transfer of H2S, COS, CS2, CO2, H2, N2, CO, CH4, and C2H6. Additional compounds will be added to this list as the experimental program moves into the gasification of coal.

The calculational technique described accounts for the mass and heat transfer resistances in both the liquid and gas phases. Solvent evaporation is also incorporated into the calculation. It is an essentially rigorous solution to a highly non-linear set of partial differential equations which treats a packed column as a true differential device without resorting to a stage -wise, tray tower analogy (Feintuch, 1978). The method involves dividing the tower height into differential sections and satisfying heat transfer, mass transfer, and equilibrium relationships for each section. Experimental verification of this technique for air-water-ammonia systems at ambient pressure and temperature has been shown by Raal and Khurana (1973). Feintuch (1978) suggests an extension of this technique to complex multicomponent systems but no literature data are available with which to compare the results. Initial indications from our work indicate that this calculational method applies to the multicomponent system studied here.

As a first step in model development, computer simulation for the adiabatic absorption of CO_2 in methanol was tried. Results for a recent synthetic gas run (AM-32) are presented in Figure 22. Here, the liquid temperature profile in the absorber is compared to the model prediction. Process conditions for AM-32 are shown in Table 12. Thus far, excellent agreement between model prediction and experimental data has been seen for column temperature profiles and removal efficiencies. The model also predicts both liquid and gas flow rate and composition profiles for both design and analysis approaches to packed column performance. The model has been used for simulation of systems containing H_2S-N_2- CH_3OH and COS-N_2-CH_3OH. A multicomponent case is presently being developed for the components mentioned above. An upcoming EPA technical report will provide a more detailed description of mathematical modeling efforts.

FIGURE 22

PACKED ABSORPTION COLUMN
LIQUID TEMPERATURE PROFILE FOR
SYNGAS RUN AM-32

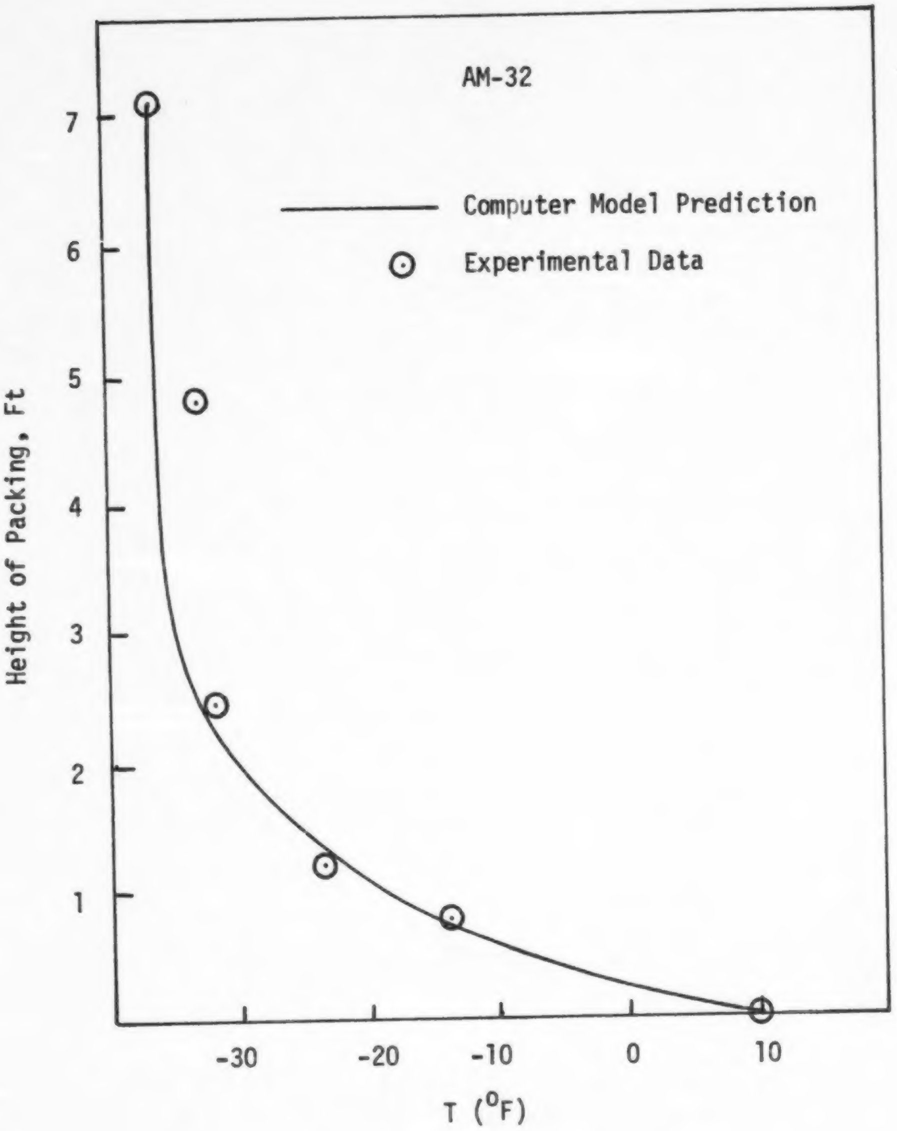


TABLE 12

PROCESS CONDITIONS FOR SYNTHETIC GAS RUN AM-32

Liquid Flow Rate	61.05 lb moles/hr/ft^2
T_L in	-36.1F
Gas Flow Rate	17.31 lb moles/hr/ft^2
T_G in	57.4°F
Pressure	28.0 Atmospheres absolute
Inlet Gas Composition	33.73 mole percent CO_2 66.27 mole percent N_2
Outlet Gas Composition	0.92 mole percent CO_2 99.08 mole percent N_2
CO_2 Removal Efficiency	98.10%

SUMMARY

The results of the experimental program to date clearly show that acid gases can be separated from sour gas streams produced by coal gasification. Furthermore, the acid gases CO_2, H_2S and COS distribute in product streams according to their relative solubilities; there is no unusual accumulation of carbonyl sulfide (COS) or any hydrocarbons in the acid gas removal system.

CONCLUSIONS AND FUTURE WORK

A total of 61 gasifications runs were made using the pilot plant facility with Western Kentucky No. 11 coal char as the gasifier feed. In eight of these runs, the product gas was fed to the AGRS using refrigerated methanol as the solvent. The first 13 gasifier runs and the first four AGRS runs were used for the development of sampling and analysis methods. The major objectives of these early runs were to achieve smooth, steady state operation and closed mathematical models for the gasifier and the AGRS, further development of sampling and analysis techniques, and assessment of the environmental problems associated with the gasification and gas cleaning of a pretreated coal char.

The Western Kentucky coal char used in these studies has a very low volatile matter content and a relatively high sulfur and trace metal content (See Appendix A), and thus was an excellent feed for startup and development purposes. During operation, the gasifier provided a make gas sufficiently high in sulfur content for a good test of the AGRS, and sufficiently high in both trace metals and sulfur gases to aid in the development of sampling and analysis methods. Since the feed char is very low in volatile matter, very little tar or other hydrocarbons were ever detected above trace levels in any water samples, or in the methyl alcohol solvent after use.

The gasifier runs using coal char have provided 27 runs which satisfied mass balance criteria. These runs have been adequate for relating gasifier performance to operating parameters, and have provided data for modeling of the reactor.

The average bed temperature and the molar steam to carbon ratio are the two most important factors in determining the make gas flow rate. Small changes in the average bed temperature can cause significant changes in the make gas flow rate. Increasing the steam to carbon ratio, in addition to increasing the make gas flow rate, reduces the tendency to produce clinkers.

An analysis of runs GO-43 through GO-61, for which good sulfur gas analyses were made, was made to evaluate the composition of the gases leaving the gasifier. Within experimental accuracy, it was found that the gases H_2S, COS, CO_2, H_2, and H_2O are in equilibrium as they leave the reactor. Therefore, if the sulfur conversion can be predicted, the concentration of the major sulfur gases in the make gas can be predicted. A rough approximation of the sulfur gas production rate may be made by assuming that the sulfur conversion equals the carbon conversion equals the carbon conversion; however, this will generally underpredict the rate of sulfur gas production. Further work on the modeling of sulfur gas production is necessary.

A sample train consisting of a cold-trap condenser followed by a series of nitric acid impingers was used to recover arsenic and lead from the make gas produced in a fluidized bed coal gasification reactor. Arsenic was present almost exclusively in the sample train condensate, while lead was found in both the condensate and impinger solutions. A gold amalgamation column was effective in recovering mercury from the gas, although a second column in series will be required to demonstrate complete recovery.

The mass balances and enrichment ratios determined for arsenic, lead, and mercury show that all three elements are volatilized in gasification, and recondense to varying degrees as the product gas cools and leaves the gasification zone. Arsenic is the least volatile of the three trace elements and is essentially completely removed in the condensed effluents. A negligible amount of arsenic is expected to be present in the sour gas that enters the acid gas removal system. Lead behaves similarly to arsenic, except that it remains more volatile as the gas cools and is removed to a lesser extent than arsenic in the condensed effluents.

Mercury is the most volatile of the three trace elements. It is almost completely volatilized, and is not effectively removed in the condensed effluents. Prior to the use of the gold amalgamation column, less than 50% of the mercury could be accounted for. The use of the amalgamation system closed the mercury mass balance to within 15% in the one run in which the system was tested.

At the present time, the gasification of a New Mexico subbituminous coal is being performed in the North Carolina State University pilot plant. As part of these studies, a designed series of experiments will be performed to correlate the emissions of arsenic, mercury, lead, and possibly other elements, with gasifier operating conditions--principally temperature, pressure, and steam-to-carbon feed ratio. The uncertainties in the feed concentrations of the elements tat characterized the runs reported in this study will be reduced through careful homogenization of the coal and multiple sampling prior to each run. The trace element emissions will be compared with predicted values based on batch gasification studies also being performed at this institution.

The reactor model, a simple single-stage model, describes the reactor performance reasonably well. The optimal model parameter values, char reactivity $f_o = 0.50$, CO/CO_2 distribution coefficient $a = 0.95$, and shift reactivity $f_{wg} = 9.9 \times 10^{-62}$, yield predicted values of the carbon conversion, make gas flow rate, and make gas composition which compare well with measured values. The incorporation of shift reaction kinetics into the model gives improved results compared to the assumption of shift reaction equilibrium. In view of the large temperature differences between the bottom and the top of the bed (up to 100 F in some runs), the use of the average bed temperature in the gasifier model probably accounts for many of the inaccuracies of the model predictions. Using a multi-region model should provide an improvement.

In a series of integrated runs, distributions of the major acid gases (CO_2, H_2S, COS) were examined as a function of system parameters. It was determined that differences in solubility among the acid gases can be used to explain the distribution of the gases. It is particularly noteworthy to gases; i.e. it distributed according to its predicted solubility. Furthermore, no difficulty was encountered in regenerating the solvent, even though it is believed that the methanol was not completely stripped under the system operating conditions. It was also found that CO_2 may be concentrated through flashing the methanol leaving the absorber. Flow meter calibrations that account for stream compositions were used to obtain closures of total and component mass balances to within a few percent. This lends credibility to sampling and analytical procedures, system performance and the hypothesis of steady state operation.

In four integrated runs, an acid gas removal efficiency of at least 94.0% was obtained for the range of operating conditions used. Also, only small differences in component removal efficiencies can be seen despite changes in packed height, liquid flow rate, and operating pressure. These observations can be explained by examining the feed gas compositions for each run and by considering mass transfer limitations brought about by residual acid gases in the solvent fed to the absorber.

The CO_2 content of the gas stream fed to the AGRS is, perhaps, the most significant factor in determining the performance of the absorber. This is because of its relatively high concentration and the exotherm of absorption associated with the dissolution of CO_2 in methanol, which affects the absorber column temperature profile and concomitantly the absorption of all other acid gases.

It was also determined that the amount of residual acid gases remaining in the methanol exiting the stripper is significant. Results of the series of integrated runs show that significant amounts of H_2S were present in the stripped methanol and, accordingly, removal efficiencies of the acid gases in the absorber were less than would have been obtained with better stripping of the recirculating methanol. Since these runs were made, a heater has been installed in the solvent line to the stripper so that the inlet stripper temperature can now be controlled. This provides for more complete stripping of the solvent and has improved the overall operation.

After approximately 60 hours of operating on gases produced from char, analyses of methanol were performed to determine accumulation of various constituents in the system. These analyses showed that there was no apparent buildup of hydrocarbons or other species in the methanol.

The results from these runs clearly point to the need to develop a mathematical model to assist with the analysis of experimental results and provide a basis for analyzing more complicated process configurations. Although there exists the possibility of feeding synthetic gas streams to the AGRS, the most useful information comes from runs where gasifier product gas is used. Because of the variability associated with gasifier operation, a carefully structured experimental plan would be difficult to complete. The strategy used thus far has been to cover a wide range of operating conditions and use a mathematical model to extend these results of process situations.

Figure 23 and Table 13 illustrate the present scope of the acid gas removal research program and plans for future work. Currently, we anticipate using a chemical solvent following the evaluation of refrigerated methanol and this work should begin somtime during 1981. A full evaluation of each solvent used includes experimental runs with both crude coal gas and synthetic gas mixtures. A computer simulation package for each system is planned. Also, vapor-liquid equilibrium model development will parallel all anticipated pilot plant studies. Capability to measure both binary and multicomponent VLE information exists and has already been utilized. This collection of information, along with an assessment of the fate of certain trace compounds, should provide the basis for evaluating the relative merits of the solvents proposed for acid gas removal in coal gasification processes.

FIGURE 23

AGRS RESEARCH PROGRAM

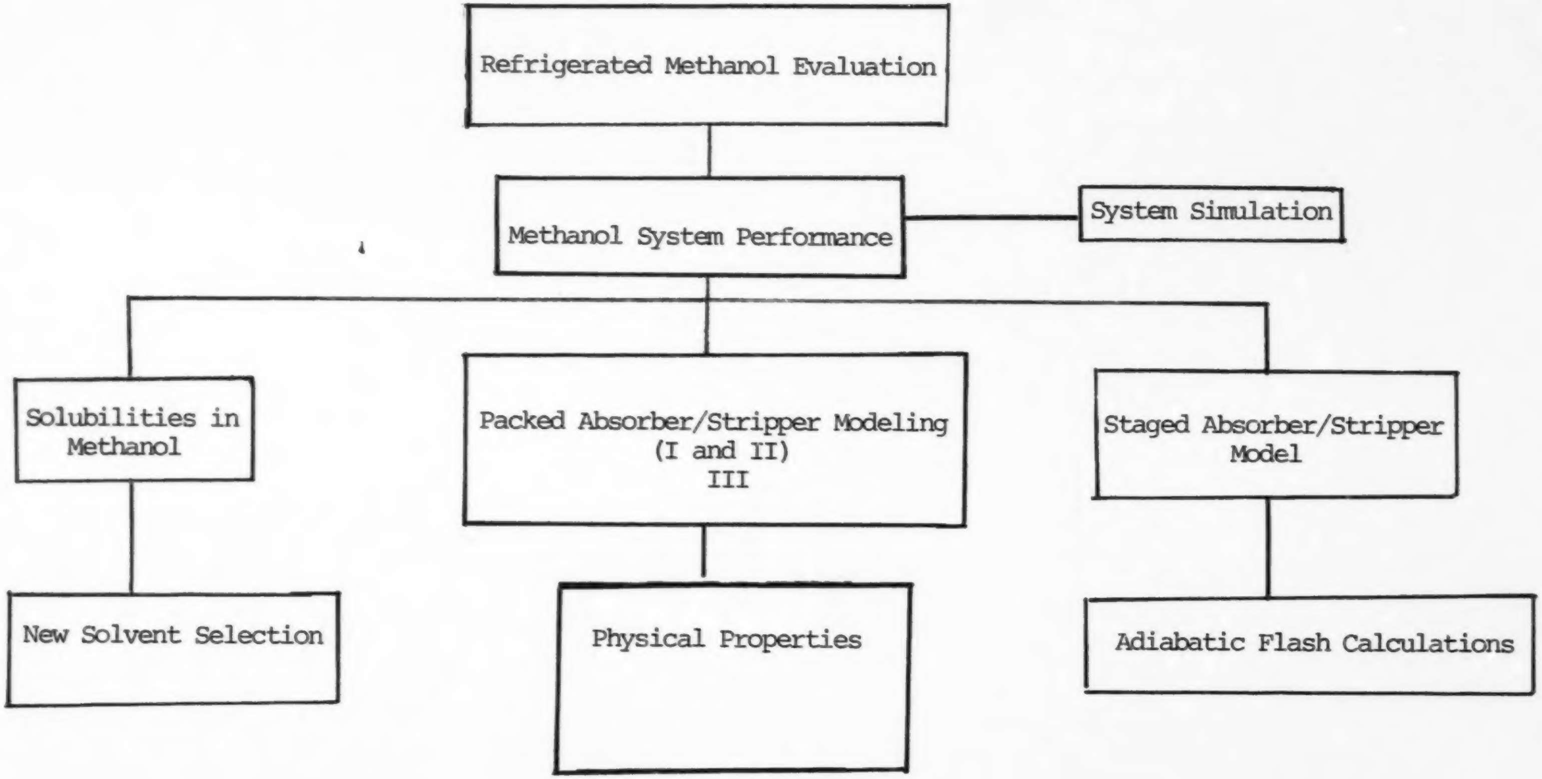

Refrigerated Methanol Evaluation
Methanol System Performance
System Simulation
Solubilities in Methanol
Packed Absorber/Stripper Modeling (I and II) III
Staged Absorber/Stripper Model
New Solvent Selection
Physical Properties
Adiabatic Flash Calculations

TABLE 13

A. Methanol System Performance
   1. CO_2, H_2S, COS and other sulfur gas removal
   2. Hydrocarbons, particularly aromatics, removal and accumulation in solvent
   3. Thermal behavior
   4. Relationship of gasifier operation to AGRS performance
   5. Comparison of SYNGAS and crude coal gas operations
   6. Methanol losses from absorber, flash tank and stripper
   7. Solvent stability

B. Solubilities in Methanol
   1. Use current VLE model (Ferrell, Rousseau and Matange, 1980) in absorber/stripper/flash tank calculations
   2. Use current VLE model to develop methods for calculating heats of solution
   3. Obtain VLE data on COS, CS_2, and other important gases, and incorporate into VLE model
   4. Modify current model to use Wilson and/or UNIQUAC equations

C. Packed Absorber/Stripper Models I, II, and III

Model I (SIMPAK): considers a three-component system in which the carrier gas is insoluble

Model II (MCOMP): places no restrictions on number of components or solubility of carrier gas

Model III (von Stockar method): relies on an unsteady state description of the packed column, and is believed to have better convergence properties than approach of Model I and II
   1. Model development for packed columns
   2. Use of model in simulation of SYNGAS operation
   3. Use of model in evaluation of crude coal gas operation
   4. Use of model to guide selection of AGRS operating variables (e.g. N_2 flow rate to stripper to maximize sulfur concentration of feed stream to sulfur recovery unit.)

D. Adiabatic Flash Calculation
   1. Model flash tank in AGRS
   2. Describe flashing process as liquid enters stripper

E. Physical Properties and Equipment Parameters
   1. Document, catalog and make available all physical properties, diffusivities and packing characteristics used in system

F. System Simulation
   1. Bring all system elements together in a program to examine unit interactions and optimize operating conditions

G. Staged Absorber/Stripper Model
   1. Extension of Packed column models to staged columns to provide

necessary tools for system simulation

H. New Solvent Selection
   1. Begin to consider next solvent system to study (e.g. hot potassium carbonate) and determine needed information to begin evaluation
   2. Determine advantages/disadvantages of potential solvents
   3. Provide basis for choosing desirable features of acid gas removal solvents from environmental, process, and energy considerations

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APPENDIX A

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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                      *
                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
                    *                                      *
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                          RUN GO-14  2/20/79  12:30-13:15


        REACTOR SPECIFICATIONS
                                                      FEED RATES AND RATIOS
 PRESSURE      = 103.0 PSIG ( 811.3 KPA)
 TEMPERATURE   = 1790.3 DEG.F ( 976.8 DEG.C)      COAL        = 31.20 LB/HR (14.15 KG/HR)
 BED HEIGHT    = 38.0 IN. (0.97 METERS)           STEAM       = 24.90 LB/HR (11.29 KG/HR)
 BED DIAMETER =   6.0 IN. (0.152 METERS)          OXYGEN      =  9.51 LB/HR ( 4.32 KG/HR)
 ESTIMATED BED VOIDAGE = 0.79                     NITROGEN    = 10.51 LB/HR ( 4.77 KG/HR)
 SOLIDS HOLDUP = 14.6 LB ( 6.6 KG)                PURGE N2    =  9.62 LB/HR ( 4.37 KG/HR)
                                                  STEAM/CARBON = 0.63 MOLES STEAM/MOLE C
                                                  O2/CARBON    = 0.14 MOLES O2/MOLE C
                                                  N2/O2        = 1.26 MOLES N2/MOLE O2


                     ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H        O        N        S

             COAL     31.2    26.33     0.16     0.12     0.11    0.892
             GASES    54.5     0.00     2.79    31.63    20.13    0.000
       TOTAL INPUT    85.7    26.33     2.95    31.74    20.24    0.892

             CHAR     20.8    17.38     0.03     0.36     0.10    0.432
             DUST      0.9     0.60     0.02     0.17     0.00    0.035
             GASES    67.2     9.81     3.40    33.82    20.14    0.000
        WASTEWATER     0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT    88.9    27.78     3.44    34.35    20.24    0.466

      % RECOVERY    103.7%   105.5%   116.8%   108.2%   100.0%    52.2%



                                          EXPERIMENTAL     MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                         14.3
         GASIFICATION                                       19.6
         TOTAL                                37.2          33.9

      DRY MAKE GAS FLOW RATE (SCFM)           13.4          11.5

      HEATING VALUE OF SWEET GAS (BTU/SCF)   267.0         249.7

      EFFLUENT FLOW RATES (LB/HR)
               CO                             11.68         10.01
               H2                              1.42          0.90
               CH4                             0.34          0.40
               CO2                            16.66         15.82
               N2                             20.14         20.16
               H2S                             0.000         0.327
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN 60-15  4-3-79  17:15-18:45


          REACTOR SPECIFICATIONS                         FEED RATES AND RATIOS

PRESSURE     = 100.8 PSIG ( 796.3 KPA)          COAL      = 25.55 LB/HR (11.59 KG/HR)
TEMPERATURE  = 1786.8 DEG.F ( 974.9 DEG.C)      STEAM     = 24.88 LB/HR (11.29 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN    =  8.82 LB/HR ( 4.00 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  =  6.67 LB/HR ( 3.03 KG/HR)
ESTIMATED BED VOIDAGE = 0.79                    PURGE N2  = 11.75 LB/HR ( 5.33 KG/HR)
SOLIDS HOLDUP = 14.9 LB ( 6.8 KG)               STEAM/CARBON = 0.79 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.16 MOLES O2/MOLE C
                                                N2/O2        = 0.86 MOLES N2/MOLE O2


                        ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                        MASS      C        H        O        N        S

              COAL      25.5    20.91     0.13     0.34     0.13    0.646
             GASES      52.1     0.00     2.78    30.91    18.43    0.000
       TOTAL INPUT      77.7    20.91     2.91    31.25    18.55    0.646

              CHAR      14.0    11.06     0.06     0.09     0.07    0.368
              DUST       0.8     0.64     0.00     0.01     0.01    0.021
             GASES      63.1     9.40     3.01    31.96    18.48    0.244
        WASTEWATER       0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT      77.9    21.09     3.07    32.06    18.55    0.633

      % RECOVERY      100.3%   100.9%   105.3%   102.6%   100.0%    97.9%



                                            EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                         16.7
         GASIFICATION                                       23.5
         TOTAL                                    44.9      40.2

       DRY MAKE GAS FLOW RATE (SCFM)              12.2      10.8

       HEATING VALUE OF SWEET GAS (BTU/SCF)      283.0     278.7

       EFFLUENT FLOW RATES (LB/HR)
                CO                               11.60      9.24
                H2                                1.19      0.87
                CH4                               0.20      0.39
                CO2                              15.63     15.20
                N2                               18.48     18.45
                H2S                               0.225     0.268
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                          RUN GO-16  5/8/79  12:45-14:15


        REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE      =  99.8 PSIG ( 789.4 KPA)         COAL        = 30.70 LB/HR (13.93 KG/HR)
TEMPERATURE   = 1778.8 DEG.F ( 970.4 DEG.C)     STEAM       = 26.10 LB/HR (11.84 KG/HR)
BED HEIGHT    = 52.0 IN. (1.32 METERS)          OXYGEN      = 10.37 LB/HR ( 4.70 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  =  5.47 LB/HR ( 2.48 KG/HR)
ESTIMATED BED VOIDAGE = 0.79                    PURGE N2  =  2.39 LB/HR ( 1.08 KG/HR)
SOLIDS HOLDUP = 19.8 LB ( 9.0 KG)               STEAM/CARBON = 0.70 MOLES STEAM/MOLE C
                                                O2/CARBON     = 0.16 MOLES O2/MOLE C
                                                N2/O2         = 0.60 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                    MASS      C       H       O       N       S

            COAL    30.7    25.02   0.49    0.04    0.32    0.773
           GASES    44.3     0.00   2.92   33.54    7.86    0.000
     TOTAL INPUT    75.0    25.02   3.41   33.58    8.18    0.773

            CHAR    16.7    12.65   0.63    0.02    0.14    0.420
            DUST     0.6     0.49   0.00    0.01    0.01    0.016
           GASES    56.8    10.95   3.09   34.42    8.02    0.316
      WASTEWATER     0.0     0.00   0.00    0.00    0.00    0.000
    TOTAL OUTPUT    74.1    24.09   3.72   34.46    8.17    0.753

    % RECOVERY     98.8%    96.3%  109.1%  102.6%   99.9%   97.3%


                                          EXPERIMENTAL   MODEL

    CARBON CONVERSION (PERCENT)
      COMBUSTION                                          16.4
      GASIFICATION                                        21.0
      TOTAL                                  43.7         37.4

     DRY MAKE GAS FLOW RATE (SCFM)           10.7          9.4

     HEATING VALUE OF SWEET GAS (BTU/SCF)   304.6        298.3

     EFFLUENT FLOW RATES (LB/HR)
              CO                            14.06        10.42
              H2                             1.16         1.02
              CH4                            0.47         0.46
              CO2                           16.72        16.64
              N2                             8.02         7.98
              H2S                            0.316        0.304
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                       RUN GO-17  5/22/79 11:00-12:45


      REACTOR SPECIFICATIONS
                                                  FEED RATES AND RATIOS
 PRESSURE      = 102.0 PSIG ( 804.6 KPA)
 TEMPERATURE   = 1778.6 DEG.F ( 970.4 DEG.C)    COAL        = 52.25 LB/HR (23.70 KG/HR)
 BED HEIGHT    = 38.0 IN. (0.97 METERS)         STEAM       = 73.80 LB/HR (33.48 KG/HR)
 BED DIAMETER =  6.0 IN. (0.152 METERS)         OXYGEN      = 15.16 LB/HR ( 6.88 KG/HR)
 ESTIMATED BED VOIDAGE = 0.78                   NITROGEN   =  2.76 LB/HR ( 1.25 KG/HR)
 SOLIDS HOLDUP = 15.0 LB ( 6.8 KG)              PURGE N2   =  5.37 LB/HR ( 2.44 KG/HR)
                                                STEAM/CARBON = 1.15 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.13 MOLES O2/MOLE C
                                                N2/O2        = 0.21 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                    MASS     C       H       O       N       S

             COAL   52.3   42.59    0.83    0.06    0.54   1.316
            GASES   97.1    0.00    8.26   80.70    8.13   0.000
      TOTAL INPUT  149.3   42.59    9.08   80.76    8.66   1.316

             CHAR   32.1   24.32    1.21    0.04    0.27   0.808
             DUST    3.3    2.68    0.01    0.06    0.03   0.088
            GASES  118.9   12.88    9.34   87.74    8.37   0.515
       WASTEWATER    0.0    0.00    0.00    0.00    0.00   0.000
     TOTAL OUTPUT  154.3   39.88   10.56   87.84    8.67   1.412

     % RECOVERY   103.3%   93.6%  116.2%  108.8%  100.0%  107.2%



                                           EXPERIMENTAL   MODEL
     CARBON CONVERSION (PERCENT)
        COMBUSTION
        GASIFICATION                                        14.1
        TOTAL                                               21.9
                                              30.2          36.0

     DRY MAKE GAS FLOW RATE (SCFM)            13.0          15.2

     HEATING VALUE OF SWEET GAS (BTU/SCF)    332.2         341.2

     EFFLUENT FLOW RATES (LB/HR)
              CO
              H2                              10.26         16.47
              CH4                              1.57          1.92
              CO2                              0.54          0.79
              N2                              29.58         28.09
              H2S                              8.37          8.31
                                               0.539         0.507
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                         * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                         * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                                RUN GO-18  5/22/79  14:00-14:45


       REACTOR SPECIFICATIONS                                    FEED RATES AND RATIOS

PRESSURE      = 102.4 PSIG ( 807.3 KPA)                COAL       = 52.60 LB/HR (23.86 KG/HR)
TEMPERATURE   = 1872.0 DEG.F (1022.2 DEG.C)            STEAM      = 73.81 LB/HR (33.48 KG/HR)
BED HEIGHT    = 38.0 IN. (0.97 METERS)                 OXYGEN     = 20.86 LB/HR ( 9.46 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)                 NITROGEN   =  2.89 LB/HR ( 1.31 KG/HR)
ESTIMATED BED VOIDAGE = 0.80                           PURGE N2   =  5.18 LB/HR ( 2.35 KG/HR)
SOLIDS HOLDUP = 13.7 LB ( 6.2 KG)                      STEAM/CARBON = 1.15 MOLES STEAM/MOLE C
                                                       O2/CARBON    = 0.18 MOLES O2/MOLE C
                                                       N2/O2        = 0.16 MOLES N2/MOLE O2



                     ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H        O        N        S

              COAL    52.6    42.88     0.83     0.06     0.54    1.325
             GASES   102.7     0.00     8.26    86.41     8.07    0.000
       TOTAL INPUT   155.3    42.88     9.09    86.47     8.61    1.325

              CHAR    31.7    24.01     1.19     0.04     0.26    0.798
              DUST     3.3     2.64     0.01     0.06     0.03    0.087
             GASES   128.8    18.01     9.71    92.13     8.32    0.652
        WASTEWATER     0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT   163.8    44.67    10.91    92.23     8.61    1.537

      % RECOVERY    105.5%   104.2%   120.1%   106.7%   100.0%   116.0%



                                               EXPERIMENTAL    MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                             19.2
         GASIFICATION                                           32.7
         TOTAL                                     42.0         51.9

       DRY MAKE GAS FLOW RATE (SCFM)               18.7         21.0

       HEATING VALUE OF SWEET GAS (BTU/SCF)       339.4        345.8

       EFFLUENT FLOW RATES (LB/HR)
                 CO                               15.64        27.31
                 H2                                2.61         2.71
                 CH4                               0.75         1.11
                 CO2                              39.34        35.59
                 N2                                8.32         8.35
                 H2S                                0.680        0.733
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                 * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                 * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                      RUN G0-19  6/19/79  12:30-13:30


       REACTOR SPECIFICATIONS
                                                      FEED RATES AND RATIOS
PRESSURE      = 101.9 PSIG ( 803.9 KPA)
TEMPERATURE   = 1761.3 DEG.F ( 960.7 DEG.C)      COAL         = 31.80 LB/HR (14.42 KG/HR)
BED HEIGHT    = 52.0 IN. (1.32 METERS)           STEAM        = 37.05 LB/HR (16.81 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)           OXYGEN       = 13.75 LB/HR ( 6.24 KG/HR)
ESTIMATED BED VOIDAGE = 0.75                     NITROGEN  =  3.68 LB/HR ( 1.67 KG/HR)
SOLIDS HOLDUP = 23.3 LB (10.6 KG)                PURGE N2  =  7.50 LB/HR ( 3.40 KG/HR)
                                                 STEAM/CARBON = 0.97 MOLES STEAM/MOLE C
                                                 02/CARBON    = 0.20 MOLES 02/MOLE C
                                                 N2/02        = 0.31 MOLES N2/MOLE 02


              ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                    MASS      C       H       O       N       S

          COAL      31.8   25.57    0.16    0.82    0.17   0.857
         GASES      62.0    0.00    4.14   46.65   11.18   0.000
   TOTAL INPUT      93.8   25.57    4.30   47.48   11.35   0.857

          CHAR      15.9   12.68    0.06    0.40    0.15   0.314
          DUST       0.9    0.51    0.01    0.07    0.00   0.014
         GASES      78.3   12.47    4.71   49.57   11.20   0.319
    WASTEWATER       0.0    0.00    0.00    0.00    0.00   0.000
  TOTAL OUTPUT      95.0   25.67    4.78   50.05   11.35   0.647

  % RECOVERY      101.3%  100.4%  111.1%  105.4%  100.0%   75.5%



                                              EXPERIMENTAL   MODEL
  CARBON CONVERSION (PERCENT)
     COMBUSTION                                               21.2
     GASIFICATION                                             24.6
     TOTAL                                        48.8        45.8

  DRY MAKE GAS FLOW RATE (SCFM)                   12.9        11.6

  HEATING VALUE OF SWEET GAS (BTU/SCF)           326.0       321.4

  EFFLUENT FLOW RATES (LB/HR)
               CO                                13.22       11.43
               H2                                 1.41        1.12
               CH4                                0.54        0.51
               CO2                               23.42       23.54
               N2                                11.20       11.24
               H2S                                0.335       0.406
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN-GO-19A  6/26/79  11:15-11:40


        REACTOR SPECIFICATIONS                               FEED RATES AND RATIOS

PRESSURE     = 102.0 PSIG ( 804.6 KPA)               COAL       = 26.60 LB/HR (12.07 KG/HR)
TEMPERATURE  = 1777.9 DEG.F ( 969.9 DEG.C)           STEAM      = 36.93 LB/HR (16.75 KG/HR)
BED HEIGHT   = 52.0 IN. (1.32 METERS)                OXYGEN     = 12.51 LB/HR ( 5.67 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)               NITROGEN   =  4.05 LB/HR ( 1.84 KG/HR)
ESTIMATED BED VOIDAGE = 0.77                         PURGE N2   =  9.07 LB/HR ( 4.12 KG/HR)
SOLIDS HOLDUP = 22.0 LB (10.0 KG)                    STEAM/CARBON = 1.15 MOLES STEAM/MOLE C
                                                     O2/CARBON    = 0.22 MOLES O2/MOLE C
                                                     N2/O2        = 0.37 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H        O        N        S

              COAL    26.6    21.39     0.13     0.69     0.15    0.717
             GASES    62.6     0.00     4.13    45.30    13.13    0.000
       TOTAL INPUT    89.2    21.39     4.26    45.99    13.28    0.717

              CHAR    10.8     8.62     0.04     0.27     0.10    0.213
              DUST     0.6     0.37     0.00     0.05     0.00    0.010
             GASES    78.2    12.53     4.51    47.58    13.17    0.372
        WASTEWATER     0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT    89.6    21.52     4.55    47.91    13.28    0.595

      % RECOVERY     100.5%   100.6%   106.8%   104.2%   100.0%    83.0%



                                              EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                          23.1
         GASIFICATION                                        30.1
         TOTAL                                    58.6       53.2

       DRY MAKE GAS FLOW RATE (SCFM)              13.4       12.0

       HEATING VALUE OF SWEET GAS (BTU/SCF)      323.3      318.3

       EFFLUENT FLOW RATES (LB/HR)
                      CO                          13.91      11.57
                      H2                           1.42       1.15
                      CH4                          0.56       0.52
                      CO2                         22.53      22.10
                      N2                          13.17      13.19
                      H2S                          0.387      0.398
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                 * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                 * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                      RUN GO-20  7/11/79  13:00-14:00


      REACTOR SPECIFICATIONS                         FEED RATES AND RATIOS

PRESSURE     = 106.5 PSIG ( 835.6 KPA)          COAL       = 28.70 LB/HR (13.02 KG/HR)
TEMPERATURE  = 1881.5 DEG.F (1027.5 DEG.C)      STEAM      = 44.14 LB/HR (20.02 KG/HR)
BED HEIGHT   = 52.0 IN. (1.32 METERS)           OXYGEN     = 22.13 LB/HR (10.04 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN   =  6.97 LB/HR ( 3.16 KG/HR)
ESTIMATED BED VOIDAGE = 0.83                    PURGE N2   =  2.15 LB/HR ( 0.98 KG/HR)
SOLIDS HOLDUP = 15.8 LB ( 7.2 KG)               STEAM/CARBON = 1.26 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.35 MOLES O2/MOLE C
                                                N2/O2        = 0.36 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                     MASS      C        H        O        N        S

            COAL     28.7    23.40     0.17     0.90     0.32    0.766
           GASES     75.4     0.00     4.94    61.32     9.13    0.000
     TOTAL INPUT    104.1    23.40     5.11    62.22     9.44    0.766

            CHAR      2.2     0.86     0.01     0.01     0.01    0.029
            DUST      0.3     0.19     0.00     0.02     0.00    0.005
           GASES    103.1    24.07     5.26    63.55     9.43    0.763
      WASTEWATER      0.0     0.00     0.00     0.00     0.00    0.000
    TOTAL OUTPUT    105.5    25.11     5.27    63.57     9.44    0.796

    % RECOVERY     101.4%   107.3%   103.1%   102.2%   100.0%   103.9%



                                            EXPERIMENTAL   MODEL

    CARBON CONVERSION (PERCENT)
      COMBUSTION                                           37.4
      GASIFICATION                                         38.7
      TOTAL                                     102.8      76.1

     DRY MAKE GAS FLOW RATE (SCFM)               21.4      15.3

     HEATING VALUE OF SWEET GAS (BTU/SCF)       321.7     305.9

     EFFLUENT FLOW RATES (LB/HR)
             CO                                 34.62     19.62
             H2                                  2.40      1.48
             CH4                                 0.80      0.60
             CO2                                31.56     32.68
             N2                                  9.43      9.35
             H2S                                 0.780     0.609
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN GO-22  7/11/79  10:35-11:25


        REACTOR SPECIFICATIONS                                FEED RATES AND RATIOS

 PRESSURE      = 103.7 PSIG ( 816.3 KPA)                COAL        = 23.70 LB/HR (10.75 KG/HR)
 TEMPERATURE  = 1868.6 DEG.F (1020.3 DEG.C)             STEAM       = 30.30 LB/HR (13.74 KG/HR)
 BED HEIGHT    = 52.0 IN. (1.32 METERS)                 OXYGEN      = 18.06 LB/HR ( 8.19 KG/HR)
 BED DIAMETER =  6.0 IN. (0.152 METERS)                 NITROGEN  =  6.89 LB/HR ( 3.12 KG/HR)
 ESTIMATED BED VOIDAGE = 0.82                           PURGE N2  =  4.42 LB/HR ( 2.00 KG/HR)
 SOLIDS HOLDUP = 17.1 LB ( 7.8 KG)                      STEAM/CARBON = 1.05 MOLES STEAM/MOLE C
                                                        O2/CARBON    = 0.35 MOLES O2/MOLE C
                                                        N2/O2        = 0.44 MOLES N2/MOLE O2


                       ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                        MASS      C        H        O        N        S

              COAL      23.7    19.32     0.14     0.74     0.26    0.633
             GASES      59.7     0.00     3.39    44.97    11.31    0.000
       TOTAL INPUT      83.4    19.32     3.53    45.71    11.57    0.633

              CHAR       2.0     1.33     0.01     0.07     0.00    0.041
              DUST       0.2     0.17     0.00     0.01     0.00    0.004
             GASES      81.6    18.95     3.76    46.78    11.57    0.540
        WASTEWATER       0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT      83.8    20.44     3.76    46.87    11.57    0.585

      % RECOVERY      100.5%   105.8%   106.6%   102.5%   100.0%    92.4%



                                                   EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                                36.9
         GASIFICATION                                              37.0
         TOTAL                                        98.0         73.9

       DRY MAKE GAS FLOW RATE (SCFM)                  17.6         13.0

       HEATING VALUE OF SWEET GAS (BTU/SCF)          313.3        294.9

       EFFLUENT FLOW RATES (LB/HR)
                    CO                               28.54        16.39
                    H2                                1.85         1.12
                    CH4                               0.57         0.46
                    CO2                              23.00        25.31
                    N2                               11.57        11.49
                    H2S                               0.548        0.491
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN GO-24  7/18/79  12:00-13:15


        REACTOR SPECIFICATIONS                            FEED RATES AND RATIOS

PRESSURE     = 105.0 PSIG ( 825.3 KPA)               COAL        = 50.44 LB/HR (22.88 KG/HR)
TEMPERATURE  = 1878.1 DEG.F (1025.6 DEG.C)           STEAM       = 60.00 LB/HR (27.22 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)                OXYGEN      = 17.22 LB/HR ( 7.81 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)               NITROGEN  =  6.89 LB/HR ( 3.12 KG/HR)
ESTIMATED BED VOIDAGE = 0.57                         PURGE N2  =  5.80 LB/HR ( 2.63 KG/HR)
SOLIDS HOLDUP = 30.1 LB (13.7 KG)                    STEAM/CARBON = 1.01 MOLES STEAM/MOLE C
                                                     O2/CARBON    = 0.16 MOLES O2/MOLE C
                                                     N2/O2        = 0.46 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                     MASS      C        H        O        N        S

           COAL      50.4    39.53     0.19     1.04     0.58    1.426
          GASES      89.9     0.00     6.71    70.50    12.69    0.000
    TOTAL INPUT     140.3    39.53     6.91    71.54    13.27    1.426

           CHAR      29.8    22.13     0.10     0.11     0.08    0.526
           DUST       3.8     2.85     0.01     0.18     0.04    0.059
          GASES     112.3    16.41     7.32    74.51    13.15    0.847
     WASTEWATER       0.0     0.00     0.00     0.00     0.00    0.000
   TOTAL OUTPUT     145.9    41.39     7.43    74.80    13.27    1.431

   % RECOVERY      103.9%   104.7%   107.6%   104.6%   100.0%   100.4%


                                          EXPERIMENTAL   MODEL

   CARBON CONVERSION (PERCENT)
      COMBUSTION                                          17.2
      GASIFICATION                                        39.9
      TOTAL                                   41.5        57.1

    DRY MAKE GAS FLOW RATE (SCFM)             16.6        22.0

    HEATING VALUE OF SWEET GAS (BTU/SCF)     307.9       327.5

    EFFLUENT FLOW RATES (LB/HR)
              CO                             17.43       30.39
              H2                              1.82        2.64
              CH4                             0.64        1.13
              CO2                            30.96       31.84
              N2                             13.15       13.03
              H2S                             0.868       0.838
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                 * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                      RUN GO-25  7/18/79  14:30-18:30


        REACTOR SPECIFICATIONS                        FEED RATES AND RATIOS

PRESSURE     = 101.7 PSIG ( 802.5 KPA)           COAL        = 50.67 LB/HR (22.98 KG/HR)
TEMPERATURE  = 1862.2 DEG.F (1016.8 DEG.C)       STEAM       = 67.18 LB/HR (30.47 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)            OXYGEN      = 17.17 LB/HR ( 7.79 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)           NITROGEN  =  6.84 LB/HR ( 3.10 KG/HR)
ESTIMATED BED VOIDAGE = 0.61                     PURGE N2  =  4.69 LB/HR ( 2.13 KG/HR)
SOLIDS HOLDUP = 26.8 LB (12.2 KG)                STEAM/CARBON = 1.13 MOLES STEAM/MOLE C
                                                 O2/CARBON    = 0.16 MOLES O2/MOLE C
                                                 N2/O2        = 0.46 MOLES N2/MOLE O2


                 ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                  MASS      C       H       O       N       S

          COAL    50.7   39.71    0.19    1.05    0.58   1.432
         GASES    95.9    0.00    7.52   76.82   11.53   0.000
   TOTAL INPUT   146.5   39.71    7.71   77.87   12.11   1.432

          CHAR    30.8   22.88    0.10    0.12    0.09   0.543
          DUST     3.9    2.95    0.01    0.19    0.04   0.061
         GASES   116.6   15.73    8.07   79.98   11.98   0.800
    WASTEWATER     0.0    0.00    0.00    0.00    0.00   0.000
  TOTAL OUTPUT   151.3   41.56    8.18   80.28   12.11   1.404

  % RECOVERY    103.3%  104.7%  106.1%  103.1%  100.0%   98.0%



                                         EXPERIMENTAL   MODEL

  CARBON CONVERSION (PERCENT)
     COMBUSTION                                          17.1
     GASIFICATION                                        38.6
     TOTAL                                   39.6        55.7

   DRY MAKE GAS FLOW RATE (SCFM)             15.8        21.6

   HEATING VALUE OF SWEET GAS (BTU/SCF)     306.1       327.5

   EFFLUENT FLOW RATES (LB/HR)
              CO                             16.17       28.05
              H2                              1.76        2.66
              CH4                             0.61        1.14
              CO2                            30.53       33.78
              N2                             11.98       11.86
              H2S                             0.818       0.825
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                          RUN GO-26  6/19/79  15:00-16:00


        REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 101.0 PSIG ( 797.7 KPA)             COAL      = 30.80 LB/HR (13.97 KG/HR)
TEMPERATURE  = 1714.3 DEG.F ( 934.6 DEG.C)         STEAM     = 37.00 LB/HR (16.78 KG/HR)
BED HEIGHT   = 52.0 IN. (1.32 METERS)              OXYGEN    = 12.60 LB/HR ( 5.72 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)             NITROGEN  =  3.59 LB/HR ( 1.63 KG/HR)
ESTIMATED BED VOIDAGE = 0.75                       PURGE N2  =  6.60 LB/HR ( 2.99 KG/HR)
SOLIDS HOLDUP = 24.0 LB (10.9 KG)                  STEAM/CARBON = 1.00 MOLES STEAM/MOLE C
                                                   O2/CARBON    = 0.19 MOLES O2/MOLE C
                                                   N2/O2        = 0.32 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H        O        N        S

           COAL       30.8    24.76     0.15     0.80     0.17    0.830
          GASES       59.8     0.00     4.14    45.46    10.18    0.000
    TOTAL INPUT       90.6    24.76     4.29    46.26    10.35    0.830

           CHAR       18.8    15.06     0.07     0.17     0.15    0.358
           DUST        1.0     0.61     0.01     0.09     0.00    0.017
          GASES       70.5     9.84     4.42    45.75    10.20    0.299
     WASTEWATER        0.0     0.00     0.00     0.00     0.00    0.000
   TOTAL OUTPUT       90.3    25.50     4.49    46.01    10.35    0.674

   % RECOVERY        99.7%   103.0%   104.8%    99.5%   100.0%    81.2%



                                                 EXPERIMENTAL   MODEL

   CARBON CONVERSION (PERCENT)
      COMBUSTION                                                 20.1
      GASIFICATION                                               19.5
      TOTAL                                          39.7        39.6

    DRY MAKE GAS FLOW RATE (SCFM)                    10.4         9.8

    HEATING VALUE OF SWEET GAS (BTU/SCF)            319.9       312.5

    EFFLUENT FLOW RATES (LB/HR)
                 CO                                  8.62        8.32
                 H2                                  1.07        0.90
                 CH4                                 0.50        0.41
                 CO2                                21.13       21.77
                 N2                                 10.20       10.25
                 H2S                                 0.316       0.340
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                 * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                       RUN GO-27  7/26/79   12:15-13:15


        REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 106.1 PSIG ( 832.9 KPA)          COAL       = 42.50 LB/HR (19.28 KG/HR)
TEMPERATURE  = 1806.7 DEG.F ( 985.9 DEG.C)      STEAM      = 68.60 LB/HR (31.12 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN     = 18.61 LB/HR ( 8.44 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  =  6.81 LB/HR ( 3.09 KG/HR)
ESTIMATED BED VOIDAGE = 0.79                    PURGE N2  =  6.96 LB/HR ( 3.16 KG/HR)
SOLIDS HOLDUP = 14.4 LB ( 6.6 KG)               STEAM/CARBON = 1.32 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.20 MOLES O2/MOLE C
                                                N2/O2        = 0.42 MOLES N2/MOLE O2


                     ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H       O        N        S

              COAL    42.5    34.74     0.19     0.55     0.48    1.161
             GASES   101.0     0.00     7.67    79.52    13.77    0.000
       TOTAL INPUT   143.5    34.74     7.87    80.07    14.26    1.161

              CHAR    23.3    18.09     0.07     0.45     0.04    0.413
              DUST     2.3     1.58     0.01     0.28     0.02    0.036
             GASES   123.2    17.55     8.30    82.46    14.19    0.702
        WASTEWATER     0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT   148.8    37.23     8.38    83.19    14.26    1.152

      % RECOVERY     103.7%  107.2%   106.5%   103.9%   100.0%    99.2%


                                            EXPERIMENTAL    MODEL

      CARBON CONVERSION (PERCENT)
        COMBUSTION                                           21.2
        GASIFICATION                                         28.4
        TOTAL                                   50.5         49.6

       DRY MAKE GAS FLOW RATE (SCFM)            18.2         17.0

       HEATING VALUE OF SWEET GAS (BTU/SCF)    315.9        313.1

       EFFLUENT FLOW RATES (LB/HR)
              CO                                17.49        18.04
              H2                                 2.08         1.80
              CH4                                0.84         0.76
              CO2                               34.48        32.69
              N2                                14.19        14.00
              H2S                                0.716        0.602
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                 * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                       RUN GO-28  8/14/79  12:30-17:30


       REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 104.0 PSIG ( 818.4 KPA)             COAL       = 38.16 LB/HR (17.31 KG/HR)
TEMPERATURE  = 1820.5 DEG.F ( 993.6 DEG.C)         STEAM      = 59.59 LB/HR (27.03 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)              OXYGEN     = 16.26 LB/HR ( 7.37 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)             NITROGEN   =  4.55 LB/HR ( 2.06 KG/HR)
ESTIMATED BED VOIDAGE = 0.75                       PURGE N2   =  6.81 LB/HR ( 3.09 KG/HR)
SOLIDS HOLDUP = 17.3 LB ( 7.9 KG)                  STEAM/CARBON = 1.28 MOLES STEAM/MOLE C
                                                   O2/CARBON    = 0.20 MOLES O2/MOLE C
                                                   N2/O2        = 0.32 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                       MASS      C       H       O       N       S

               COAL    38.2   31.04    0.17    0.70    0.40   1.002
              GASES    87.2    0.00    6.67   69.17   11.35   0.000
        TOTAL INPUT   125.4   31.04    6.84   69.87   11.75   1.002

               CHAR    16.0   11.63    0.03    0.25    0.01   0.256
               DUST     1.6    0.99    0.00    0.01    0.02   0.023
              GASES   112.1   17.47    7.24   75.02   11.72   0.632
         WASTEWATER     0.0    0.00    0.00    0.00    0.00   0.000
       TOTAL OUTPUT   129.7   30.10    7.27   75.28   11.75   0.911

       % RECOVERY    103.5%   97.0%  106.2%  107.7%  100.0%   90.9%


                                            EXPERIMENTAL   MODEL

       CARBON CONVERSION (PERCENT)
          COMBUSTION                                        20.7
          GASIFICATION                                      32.8
          TOTAL                                 56.3        53.5

        DRY MAKE GAS FLOW RATE (SCFM)           17.1        16.2

        HEATING VALUE OF SWEET GAS (BTU/SCF)   335.9       328.6

        EFFLUENT FLOW RATES (LB/HR)
                   CO                          15.87       18.27
                   H2                           1.91        1.82
                   CH4                          1.11        0.78
                   CO2                         36.01       29.98
                   N2                          11.72       11.56
                   H2S                          0.647       0.550
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN GO-29  8/28/79  12:00-17:30


       REACTOR SPECIFICATIONS                              FEED RATES AND RATIOS

PRESSURE      = 104.0 PSIG ( 818.4 KPA)            COAL         = 40.72 LB/HR (18.47 KG/HR)
TEMPERATURE   = 1817.3 DEG.F ( 991.8 DEG.C)        STEAM        = 57.30 LB/HR (25.99 KG/HR)
BED HEIGHT    = 52.0 IN. (1.32 METERS)             OXYGEN       = 15.81 LB/HR ( 7.17 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)             NITROGEN  =   3.70 LB/HR ( 1.68 KG/HR)
ESTIMATED BED VOIDAGE = 0.74                       PURGE N2  =   8.75 LB/HR ( 3.97 KG/HR)
SOLIDS HOLDUP = 24.3 LB (11.0 KG)                  STEAM/CARBON = 1.13 MOLES STEAM/MOLE C
                                                   O2/CARBON    = 0.18 MOLES O2/MOLE C
                                                   N2/O2        = 0.27 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                     MASS     C       H       O       N       S

          COAL       40.7   33.68    0.22    0.73    0.43   1.059
         GASES       85.6    0.00    6.41   66.69   12.45   0.000
   TOTAL INPUT      126.3   33.68    6.63   67.42   12.88   1.059

          CHAR       18.4   12.62    0.03    0.40    0.15   0.291
          DUST        2.0    1.35    0.01    0.09    0.02   0.032
         GASES       98.5   15.64    6.49   63.07   12.72   0.586
    WASTEWATER        0.0    0.00    0.00    0.00    0.00   0.000
  TOTAL OUTPUT      118.9   29.61    6.53   63.56   12.88   0.909

  % RECOVERY        94.2%   87.9%   98.5%   94.3%  100.0%   85.9%


                                           EXPERIMENTAL   MODEL

  CARBON CONVERSION (PERCENT)
     COMBUSTION                                            18.5
     GASIFICATION                                          33.2
     TOTAL                                      46.4       51.7

   DRY MAKE GAS FLOW RATE (SCFM)                17.0       17.4

   HEATING VALUE OF SWEET GAS (BTU/SCF)        335.9      337.3

   EFFLUENT FLOW RATES (LB/HR)
               CO                              16.99      19.95
               H2                               2.12       2.00
               CH4                              0.84       0.89
               CO2                             28.26      30.08
               N2                              12.72      12.67
               H2S                              0.603      0.565
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                         * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                         * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                                RUN GO-30  9/13/79  11:00-17:00   6 CONE DISTRIBUTOR


        REACTOR SPECIFICATIONS                                 FEED RATES AND RATIOS

PRESSURE     = 103.5 PSIG ( 814.9 KPA)                 COAL      = 36.50 LB/HR (16.56 KG/HR)
TEMPERATURE  = 1830.2 DEG.F ( 999.0 DEG.C)             STEAM     = 57.30 LB/HR (25.99 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)                  OXYGEN    = 14.71 LB/HR ( 6.67 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)                 NITROGEN  =  3.73 LB/HR ( 1.69 KG/HR)
ESTIMATED BED VOIDAGE = 0.79                           PURGE N2  =  9.16 LB/HR ( 4.15 KG/HR)
SOLIDS HOLDUP = 14.6 LB ( 6.6 KG)                      STEAM/CARBON = 1.27 MOLES STEAM/MOLE C
                                                       O2/CARBON    = 0.18 MOLES O2/MOLE C
                                                       N2/O2        = 0.29 MOLES N2/MOLE O2


                             ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                              MASS       C       H       O       N       S

                      COAL    36.5   30.19    0.20    0.65    0.39   0.949
                     GASES    84.9    0.00    6.41   65.59   12.88   0.000
               TOTAL INPUT   121.4   30.19    6.61   66.24   13.27   0.949

                      CHAR    17.8   12.22    0.03    0.39    0.14   0.281
                      DUST     1.2    0.79    0.00    0.05    0.01   0.019
                     GASES   101.5   15.16    6.76   65.77   13.12   0.686
                WASTEWATER     0.0    0.00    0.00    0.00    0.00   0.000
              TOTAL OUTPUT   120.5   28.17    6.80   66.21   13.27   0.986

              % RECOVERY     99.3%   93.3%  102.9%  100.0%  100.0%  103.9%


                                                     EXPERIMENTAL   MODEL

              CARBON CONVERSION (PERCENT)
                 COMBUSTION                                          19.3
                 GASIFICATION                                        33.1
                 TOTAL                                  50.2         52.4

               DRY MAKE GAS FLOW RATE (SCFM)            16.2         16.1

               HEATING VALUE OF SWEET GAS (BTU/SCF)    336.0        333.6

               EFFLUENT FLOW RATES (LB/HR)
                         CO                            16.51        17.99
                         H2                             1.90         1.80
                         CH4                            0.87         0.77
                         CO2                           27.17        27.56
                         N2                            13.12        13.09
                         H2S                             0.677        0.519
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                    RUN GO-31  9/13/79  18:15-19:00  6 CONE DISTRIBUTOR


         REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 106.2 PSIG ( 833.3 KPA)            COAL      = 57.60 LB/HR (26.13 KG/HR)
TEMPERATURE  = 1832.7 DEG.F (1000.4 DEG.C)        STEAM     = 73.50 LB/HR (33.34 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)             OXYGEN    = 19.29 LB/HR ( 8.75 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)            NITROGEN  =  3.82 LB/HR ( 1.73 KG/HR)
ESTIMATED BED VOIDAGE = 0.78                      PURGE N2  =  8.01 LB/HR ( 3.63 KG/HR)
SOLIDS HOLDUP = 15.5 LB ( 7.1 KG)                 STEAM/CARBON = 1.03 MOLES STEAM/MOLE C
                                                  O2/CARBON    = 0.15 MOLES O2/MOLE C
                                                  N2/O2        = 0.23 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                     MASS      C       H       O       N       S

             COAL    57.6   47.64    0.31    1.03    0.61   1.498
            GASES   104.6    0.00    8.22   84.56   11.83   0.000
      TOTAL INPUT   162.2   47.64    8.54   85.58   12.45   1.498

             CHAR    35.8   24.57    0.06    0.79    0.29   0.566
             DUST     2.4    1.59    0.01    0.11    0.02   0.038
            GASES   127.9   18.73    9.04   87.02   12.13   0.938
       WASTEWATER     0.0    0.00    0.00    0.00    0.00   0.000
     TOTAL OUTPUT   166.1   44.90    9.11   87.91   12.44   1.542

     % RECOVERY    102.4%   94.2%  106.7%  102.7%   99.9%  103.0%



                                               EXPERIMENTAL   MODEL

     CARBON CONVERSION (PERCENT)
        COMBUSTION                                             16.0
        GASIFICATION                                           27.3
        TOTAL                                      39.3        43.3

      DRY MAKE GAS FLOW RATE (SCFM)                19.1        19.9

      HEATING VALUE OF SWEET GAS (BTU/SCF)        340.1       339.3

      EFFLUENT FLOW RATES (LB/HR)
              CO                                  20.08       23.97
              H2                                   2.34        2.31
              CH4                                  1.06        1.01
              CO2                                 34.15       35.35
              N2                                  12.13       12.10
              H2S                                  0.960       0.673
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                           RUN GO-34  10/10/79  11:00-12:00


        REACTOR SPECIFICATIONS                                 FEED RATES AND RATIOS

PRESSURE     = 103.9 PSIG ( 817.7 KPA)                 COAL      = 44.20 LB/HR (20.05 KG/HR)
TEMPERATURE  = 1693.7 DEG.F ( 923.1 DEG.C)             STEAM     = 39.45 LB/HR (17.89 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)                  OXYGEN    =  8.61 LB/HR ( 3.90 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)                 NITROGEN  = 17.13 LB/HR ( 7.77 KG/HR)
ESTIMATED BED VOIDAGE = 0.68                           PURGE N2  =  4.09 LB/HR ( 1.86 KG/HR)
SOLIDS HOLDUP = 22.2 LB (10.1 KG)                      STEAM/CARBON = 0.73 MOLES STEAM/MOLE C
                                                       O2/CARBON    = 0.09 MOLES O2/MOLE C
                                                       N2/O2        = 2.27 MOLES N2/MOLE O2


                        ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                         MASS      C        H        O        N        S

              COAL       44.2    36.07     0.30     0.27     0.47    1.131
             GASES       69.3     0.00     4.41    43.64    21.22    0.000
       TOTAL INPUT      113.5    36.07     4.71    43.90    21.69    1.131

              CHAR       34.1    27.79     0.13     0.20     0.27    0.729
              DUST        2.2     1.27     0.01     0.11     0.02    0.050
             GASES       74.4     5.85     4.92    41.71    21.40    0.528
        WASTEWATER        0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT      110.7    34.91     5.06    42.02    21.69    1.307

      % RECOVERY        97.6%    96.8%   107.4%    95.7%   100.0%   115.5%


                                           EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                          9.4
         GASIFICATION                                       12.3
         TOTAL                                 16.2         21.7

       DRY MAKE GAS FLOW RATE (SCFM)           10.7         11.1

       HEATING VALUE OF SWEET GAS (BTU/SCF)   196.6        196.9

       EFFLUENT FLOW RATES (LB/HR)
                 CO                            4.99         7.06
                 H2                            1.05         0.89
                 CH4                           0.37         0.39
                 CO2                          12.57        16.57
                 N2                           21.40        21.31
                 H2S                           0.540        0.269
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                          RUN GO-35  10/18/79  13:30-15:00


         REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE      = 103.4 PSIG ( 814.2 KPA)           COAL       = 44.20 LB/HR (20.05 KG/HR)
TEMPERATURE   = 1683.0 DEG.F ( 917.2 DEG.C)       STEAM      = 51.09 LB/HR (23.17 KG/HR)
BED HEIGHT    = 38.0 IN. (0.97 METERS)            OXYGEN     =  9.36 LB/HR ( 4.24 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)            NITROGEN   =  7.91 LB/HR ( 3.59 KG/HR)
ESTIMATED BED VOIDAGE = 0.70                      PURGE N2   =  7.05 LB/HR ( 3.20 KG/HR)
SOLIDS HOLDUP = 21.1 LB ( 9.6 KG)                 STEAM/CARBON = 0.94 MOLES STEAM/MOLE C
                                                  O2/CARBON    = 0.10 MOLES O2/MOLE C
                                                  N2/O2        = 0.97 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                    MASS      C        H        O        N        S

         COAL       44.2    36.07     0.30     0.27     0.47    1.131
         GASES      75.4     0.00     5.72    54.72    14.96    0.000
   TOTAL INPUT     119.6    36.07     6.01    54.99    15.43    1.131

         CHAR       31.0    25.31     0.08     0.10     0.25    0.661
         DUST        2.0     1.16     0.01     0.10     0.02    0.045
         GASES      86.6     7.93     6.33    56.66    15.17    0.518
    WASTEWATER       0.0     0.00     0.00     0.00     0.00    0.000
  TOTAL OUTPUT     119.6    34.40     6.42    56.86    15.43    1.224

  % RECOVERY      100.0%    95.4%   106.8%   103.4%   100.0%   108.2%


                                          EXPERIMENTAL   MODEL

  CARBON CONVERSION (PERCENT)
     COMBUSTION                                           10.3
     GASIFICATION                                         13.0
     TOTAL                                    22.0        23.3

   DRY MAKE GAS FLOW RATE (SCFM)              10.5        10.3

   HEATING VALUE OF SWEET GAS (BTU/SCF)      273.5       265.6

   EFFLUENT FLOW RATES (LB/HR)
            CO                                 6.41        7.47
            H2                                 1.08        0.95
            CH4                                0.55        0.40
            CO2                               17.47       17.93
            N2                                15.17       15.06
            H2S                                0.529       0.277
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                       RUN GO-36  11/15/79  11:00-12:30


         REACTOR SPECIFICATIONS
                                                      FEED RATES AND RATIOS
PRESSURE      = 104.7 PSIG ( 823.2 KPA)
TEMPERATURE   = 1782.8 DEG.F ( 972.7 DEG.C)       COAL      = 41.60 LB/HR (18.87 KG/HR)
BED HEIGHT    = 38.0 IN. (0.97 METERS)            STEAM     = 35.80 LB/HR (16.24 KG/HR)
BED DIAMETER =   6.0 IN. (0.152 METERS)           OXYGEN    = 11.65 LB/HR ( 5.29 KG/HR)
ESTIMATED BED VOIDAGE = 0.72                      NITROGEN  = 17.32 LB/HR ( 7.86 KG/HR)
SOLIDS HOLDUP = 19.1 LB ( 8.7 KG)                 PURGE N2  =  5.75 LB/HR ( 2.61 KG/HR)
                                                  STEAM/CARBON = 0.68 MOLES STEAM/MOLE C
                                                  O2/CARBON    = 0.12 MOLES O2/MOLE C
                                                  N2/O2        = 1.70 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H        O        N        S

              COAL    41.6    35.01     0.19     1.04     0.03    0.990
             GASES    70.5     0.00     4.01    43.44    23.07    0.000
       TOTAL INPUT   112.1    35.01     4.20    44.48    23.10    0.990

              CHAR    30.8    26.04     0.11     0.23     0.03    0.563
              DUST     2.7     2.18    -0.00     0.08     0.02    0.043
             GASES    77.3     9.05     4.85    39.97    23.05    0.414
        WASTEWATER     0.0     0.00     0.00     0.00     0.00    0.000
      TOTAL OUTPUT   110.8    37.28     4.95    40.28    23.10    1.019

      % RECOVERY     98.8%   106.5%   118.0%    90.5%   100.0%   103.0%



                                            EXPERIMENTAL   MODEL

     CARBON CONVERSION (PERCENT)
        COMBUSTION                                          13.2
        GASIFICATION                                        20.1
        TOTAL                                   25.9        33.3

     DRY MAKE GAS FLOW RATE (SCFM)              15.2        14.4

     HEATING VALUE OF SWEET GAS (BTU/SCF)      243.1       233.2

     EFFLUENT FLOW RATES (LB/HR)
                 CO                             9.80       12.91
                 H2                             1.90        1.24
                 CH4                            0.45        0.55
                 CO2                           16.52       20.82
                 N2                            23.05       23.08
                 H2S                            0.414       0.345
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                        RUN 60-37  11015079  14:00-15:30


         REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE      = 105.4 PSIG ( 828.0 KPA)          COAL        = 43.10 LB/HR (19.55 KG/HR)
TEMPERATURE   = 1786.9 DEG.F ( 975.0 DEG.C)      STEAM       = 50.10 LB/HR (22.73 KG/HR)
BED HEIGHT    = 38.0 IN. (0.97 METERS)           OXYGEN      = 13.58 LB/HR ( 6.16 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)           NITROGEN  =  6.23 LB/HR ( 2.82 KG/HR)
ESTIMATED BED VOIDAGE = 0.75                     PURGE N2  =  5.71 LB/HR ( 2.59 KG/HR)
SOLIDS HOLDUP = 17.3 LB ( 7.8 KG)                STEAM/CARBON = 0.92 MOLES STEAM/MOLE C
                                                 O2/CARBON    = 0.14 MOLES O2/MOLE C
                                                 N2/O2        = 0.52 MOLES N2/MOLE O2


                     ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C        H        O        N        S

           COAL       43.1    36.27     0.20     0.80     0.31    1.026
          GASES       75.6     0.00     5.60    58.07    11.94    0.000
    TOTAL INPUT      118.7    36.27     5.80    58.86    12.25    1.026

           CHAR       28.0    22.62     0.08     0.55     0.13    0.451
           DUST        2.4     1.98    -0.00     0.07     0.02    0.039
          GASES       85.5    11.81     6.25    54.78    12.10    0.518
     WASTEWATER        0.0     0.00     0.00     0.00     0.00    0.000
   TOTAL OUTPUT      115.9    36.41     6.33    55.40    12.25    1.008

   % RECOVERY        97.6%   100.4%   109.1%    94.1%   100.0%    98.3%



                                              EXPERIMENTAL    MODEL

   CARBON CONVERSION (PERCENT)
      COMBUSTION                                               14.8
      GASIFICATION                                             23.4
      TOTAL                                       32.6         38.2

    DRY MAKE GAS FLOW RATE (SCFM)                 14.7         14.1

    HEATING VALUE OF SWEET GAS (BTU/SCF)         314.4        311.7

    EFFLUENT FLOW RATES (LB/HR)
               CO                                12.27        14.94
               H2                                 2.06         1.54
               CH4                                0.68         0.69
               CO2                               22.08        25.34
               N2                                12.10        12.05
               H2S                                0.526        0.412
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN GO-38A  11-28-79  10:50-11:50


       REACTOR SPECIFICATIONS                           FEED RATES AND RATIOS

PRESSURE     = 104.9 PSIG ( 824.6 KPA)             COAL       = 34.02 LB/HR (15.43 KG/HR)
TEMPERATURE  = 1829.7 DEG.F ( 998.7 DEG.C)         STEAM      = 56.44 LB/HR (25.60 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)              OXYGEN     = 15.02 LB/HR ( 6.81 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)             NITROGEN   =  6.13 LB/HR ( 2.78 KG/HR)
ESTIMATED BED VOIDAGE = 0.77                       PURGE N2   =  9.17 LB/HR ( 4.16 KG/HR)
SOLIDS HOLDUP = 15.9 LB ( 7.2 KG)                  STEAM/CARBON = 1.33 MOLES STEAM/MOLE C
                                                   O2/CARBON    = 0.20 MOLES O2/MOLE C
                                                   N2/O2        = 0.47 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                       MASS      C       H       O       N       S

            COAL       34.0    28.33    0.18    0.71    0.08   1.054
           GASES       86.8     0.00    6.31   65.14   15.30   0.000
     TOTAL INPUT      120.8    28.33    6.49   65.85   15.39   1.054

            CHAR       13.9    11.04    0.02    0.24    0.09   0.250
            DUST        1.7     1.33    0.01    0.05    0.01   0.034
           GASES       99.8    15.71    6.30   61.80   15.29   0.658
      WASTEWATER        0.0     0.00    0.00    0.00    0.00   0.000
    TOTAL OUTPUT      115.3    28.08    6.33   62.08   15.39   0.941

    % RECOVERY        95.5%    99.1%   97.5%   94.3%  100.0%   89.3%


                                              EXPERIMENTAL   MODEL

    CARBON CONVERSION (PERCENT)
       COMBUSTION                                              20.9
       GASIFICATION                                            35.0
       TOTAL                                      55.5         55.9

     DRY MAKE GAS FLOW RATE (SCFM)                16.7         16.6

     HEATING VALUE OF SWEET GAS (BTU/SCF)        323.7        318.5

     EFFLUENT FLOW RATES (LB/HR)
              CO                                 20.18        17.87
              H2                                  1.84         1.78
              CH4                                 0.91         0.76
              CO2                                23.33        27.99
              N2                                 15.29        15.33
              H2S                                 0.674        0.625
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* FLUIDIZED BED COAL GASIFICATION REACTOR *
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             RUN GO-38B  11-28-79  12:30-15:30


      REACTOR SPECIFICATIONS
                                                       FEED RATES AND RATIOS
PRESSURE     = 104.6 PSIG ( 822.2 KPA)
TEMPERATURE  = 1829.8 DEG.F ( 998.8 DEG.C)        COAL         = 33.96 LB/HR (15.40 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)             STEAM        = 56.45 LB/HR (25.61 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)            OXYGEN       = 14.43 LB/HR ( 6.55 KG/HR)
ESTIMATED BED VOIDAGE = 0.77                      NITROGEN   =  6.13 LB/HR ( 2.78 KG/HR)
SOLIDS HOLDUP = 15.9 LB ( 7.2 KG)                 PURGE N2   =  7.80 LB/HR ( 3.54 KG/HR)
                                                  STEAM/CARBON = 1.33 MOLES STEAM/MOLE C
                                                  O2/CARBON    = 0.19 MOLES O2/MOLE C
                                                  N2/O2        = 0.49 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                       MASS      C        H        O        N        S

               COAL    34.0    28.28    0.18     0.71     0.08    1.052
              GASES    84.8     0.00    6.32    64.56    13.93    0.000
        TOTAL INPUT   118.8    28.28    6.49    65.27    14.02    1.052

               CHAR    13.5    10.76    0.02     0.23     0.09    0.244
               DUST     1.6     1.30    0.01     0.05     0.01    0.033
              GASES    98.4    15.20    6.50    62.16    13.91    0.638
         WASTEWATER     0.0     0.00    0.00     0.00     0.00    0.000
       TOTAL OUTPUT   113.6    27.25    6.53    62.43    14.01    0.914

       % RECOVERY     95.6%    96.4%  100.5%    95.6%   100.0%    86.9%



                                           EXPERIMENTAL   MODEL
       CARBON CONVERSION (PERCENT)
          COMBUSTION                                       20.2
          GASIFICATION                                     35.3
          TOTAL                                53.7        55.5

        DRY MAKE GAS FLOW RATE (SCFM)          16.2        16.2

        HEATING VALUE OF SWEET GAS (BTU/SCF)  324.7       318.7

        EFFLUENT FLOW RATES (LB/HR)
                     CO                        19.35       17.78
                     H2                         1.86        1.79
                     CH4                        0.96        0.77
                     CO2                       22.63       27.38
                     N2                        13.91       13.96
                     H2S                        0.653       0.616
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* FLUIDIZED BED COAL GASIFICATION REACTOR *
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        RUN GO-43  1-8-80  11:00-14:00


      REACTOR SPECIFICATIONS                                  FEED RATES AND RATIOS

PRESSURE      = 104.5 PSIG ( 821.8 KPA)                 COAL        = 34.05 LB/HR (15.44 KG/HR)
TEMPERATURE   = 1819.6 DEG.F ( 993.1 DEG.C)             STEAM       = 56.18 LB/HR (25.48 KG/HR)
BED HEIGHT    = 38.0 IN. (0.97 METERS)                  OXYGEN      = 14.91 LB/HR ( 6.77 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)                  NITROGEN    =  6.74 LB/HR ( 3.06 KG/HR)
ESTIMATED BED VOIDAGE = 0.76                            PURGE N2    = 13.91 LB/HR ( 6.31 KG/HR)
SOLIDS HOLDUP = 16.8 LB ( 7.6 KG)                       STEAM/CARBON = 1.31 MOLES STEAM/MOLE C
                                                        O2/CARBON    = 0.20 MOLES O2/MOLE C
                                                        N2/O2        = 0.52 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C       H       O       N       S

             COAL     34.0    28.55    0.19    0.76    0.02   0.896
            GASES     91.7     0.00    6.29   64.80   20.65   0.000
      TOTAL INPUT    125.8    28.55    6.47   65.56   20.67   0.896

             CHAR     13.6    10.76    0.05    0.43    0.02   0.218
             DUST      1.6     1.08    0.01    0.04    0.00   0.024
            GASES    115.2    18.60    5.92   69.44   20.65   0.600
       WASTEWATER      0.0     0.00    0.00    0.00    0.00   0.000
     TOTAL OUTPUT    130.4    30.44    5.97   69.92   20.67   0.842

     % RECOVERY     103.7%   106.6%   92.2%  106.6%  100.0%   94.1%


                                          EXPERIMENTAL   MODEL

     CARBON CONVERSION (PERCENT)
        COMBUSTION                                        20.6
        GASIFICATION                                      34.0
        TOTAL                                 65.1        54.6

      DRY MAKE GAS FLOW RATE (SCFM)           17.3        17.5

      HEATING VALUE OF SWEET GAS (BTU/SCF)   319.0       314.2

      EFFLUENT FLOW RATES (LB/HR)
               CO                            23.99       17.34
               H2                             1.15        1.76
               CH4                            0.99        0.75
               CO2                           27.73       27.77
               N2                            20.65       20.65
               H2S                            0.610       0.505
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                         * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                         * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                              RUN GO-44B  1/22/80  11:15-14:30


          REACTOR SPECIFICATIONS                              FEED RATES AND RATIOS

   PRESSURE     = 101.6 PSIG ( 801.7 KPA)             COAL       = 34.69 LB/HR (15.74 KG/HR)
   TEMPERATURE  = 1699.8 DEG.F ( 926.5 DEG.C)         STEAM      = 55.85 LB/HR (25.33 KG/HR)
   BED HEIGHT   = 38.0 IN. (0.97 METERS)              OXYGEN     = 10.10 LB/HR ( 4.58 KG/HR)
   BED DIAMETER =  6.0 IN. (0.152 METERS)             NITROGEN   =  6.32 LB/HR ( 2.87 KG/HR)
   ESTIMATED BED VOIDAGE = 0.74                       PURGE N2   = 14.16 LB/HR ( 6.42 KG/HR)
   SOLIDS HOLDUP = 18.4 LB ( 8.3 KG)                  STEAM/CARBON = 1.31 MOLES STEAM/MOLE C
                                                      O2/CARBON    = 0.13 MOLES O2/MOLE C
                                                      N2/O2        = 0.71 MOLES N2/MOLE O2


                         ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                          MASS      C        H        O        N        S

                COAL      34.7    28.44     0.16     1.37     0.05    0.918
               GASES      86.4     0.00     6.25    59.70    20.47    0.000
         TOTAL INPUT     121.1    28.44     6.41    61.06    20.52    0.918

                CHAR      21.8    18.10     0.08     0.53     0.08    0.412
                DUST       1.8     1.20     0.01     0.23     0.01    0.029
               GASES      96.2     8.99     6.43    59.88    20.43    0.426
          WASTEWATER       0.0     0.00     0.00     0.00     0.00    0.000
        TOTAL OUTPUT     119.8    28.29     6.52    60.64    20.52    0.866

        % RECOVERY       98.9%    99.5%   101.8%    99.3%   100.0%    94.3%



                                                EXPERIMENTAL   MODEL

        CARBON CONVERSION (PERCENT)
           COMBUSTION                                           14.0
           GASIFICATION                                         18.7
           TOTAL                                     31.6       32.7

         DRY MAKE GAS FLOW RATE (SCFM)               11.7       12.0

         HEATING VALUE OF SWEET GAS (BTU/SCF)       296.0      286.1

         EFFLUENT FLOW RATES (LB/HR)
                 CO                                  8.48       8.67
                 H2                                  0.94       1.00
                 CH4                                 0.66       0.41
                 CO2                                17.79      19.33
                 N2                                 20.43      20.48
                 H2S                                 0.434      0.297
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* FLUIDIZED BED COAL GASIFICATION REACTOR   *
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                GO-45  1/29/80  11:00-13:30


      REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 103.1 PSIG ( 812.4 KPA)           COAL       = 36.70 LB/HR (16.65 KG/HR)
TEMPERATURE  = 1696.6 DEG.F ( 924.8 DEG.C)       STEAM      = 36.63 LB/HR (16.62 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)            OXYGEN     =  8.02 LB/HR ( 3.64 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)           NITROGEN   = 33.05 LB/HR (14.99 KG/HR)
ESTIMATED BED VOIDAGE = 0.71                     PURGE N2   = 16.85 LB/HR ( 7.64 KG/HR)
SOLIDS HOLDUP = 20.4 LB ( 9.3 KG)                STEAM/CARBON = 0.81 MOLES STEAM/MOLE C
                                                 O2/CARBON    = 0.10 MOLES O2/MOLE C
                                                 N2/O2        = 4.71 MOLES N2/MOLE O2


                  ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                  MASS      C        H        O        N        S

          COAL    36.7    30.13    0.20     1.58     0.10    0.950
         GASES    94.5     0.00    4.10    40.55    49.90    0.000
   TOTAL INPUT   131.2    30.13    4.30    42.13    49.99    0.950

          CHAR    27.9    23.43    0.10     0.67     0.08    0.597
          DUST     1.5     1.06    0.01     0.13     0.01    0.026
         GASES   100.7     6.11    4.32    40.06    49.90    0.316
    WASTEWATER     0.0     0.00    0.00     0.00     0.00    0.000
  TOTAL OUTPUT   130.1    30.60    4.43    40.87    49.99    0.938

  % RECOVERY     99.1%   101.6%  103.1%   97.0%   100.0%    98.7%


                                             EXPERIMENTAL    MODEL

  CARBON CONVERSION (PERCENT)
     COMBUSTION                                               10.5
     GASIFICATION                                             14.2
     TOTAL                                       20.3         24.7

   DRY MAKE GAS FLOW RATE (SCFM)                 16.0         16.8

   HEATING VALUE OF SWEET GAS (BTU/SCF)         121.7        131.1

   EFFLUENT FLOW RATES (LB/HR)
              CO                                  5.18         7.00
              H2                                  0.73         0.80
              CH4                                 0.40         0.32
              CO2                                13.13        15.35
              N2                                 49.90        49.90
              H2S                                 0.311        0.241
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* FLUIDIZED BED COAL GASIFICATION REACTOR *
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                    GO-46  2/5/80  12:00-14:00


      REACTOR SPECIFICATIONS                         FEED RATES AND RATIOS

PRESSURE     = 103.5 PSIG ( 814.7 KPA)          COAL      = 33.18 LB/HR (15.05 KG/HR)
TEMPERATURE  = 1822.7 DEG.F ( 994.8 DEG.C)      STEAM     = 36.73 LB/HR (16.66 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN    = 12.99 LB/HR ( 5.89 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  = 23.36 LB/HR (10.59 KG/HR)
ESTIMATED BED VOIDAGE = 0.76                    PURGE N2  = 13.37 LB/HR ( 6.06 KG/HR)
SOLIDS HOLDUP = 16.6 LB ( 7.6 KG)               STEAM/CARBON = 0.88 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.18 MOLES O2/MOLE C
                                                N2/O2        = 2.05 MOLES N2/MOLE O2


             ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

              MASS      C       H       O       N       S

        COAL  33.2   27.73    0.16    1.01    0.03   0.869
       GASES  86.4    0.00    4.11   45.61   36.72   0.000
 TOTAL INPUT 119.6   27.73    4.26   46.62   36.75   0.869

        CHAR  15.8   12.14    0.05    0.08    0.01   0.290
        DUST   1.2    0.97    0.01    0.04    0.00   0.019
       GASES  98.2   11.87    4.30   44.77   36.74   0.533
  WASTEWATER   0.0    0.00    0.00    0.00    0.00   0.000
TOTAL OUTPUT 115.2   24.97    4.36   44.89   36.75   0.843

% RECOVERY   96.3%   90.0%  102.2%   96.3%  100.0%   97.1%


                                         EXPERIMENTAL   MODEL

CARBON CONVERSION (PERCENT)
   COMBUSTION                                            18.5
   GASIFICATION                                          28.7
   TOTAL                                      42.8       47.2

 DRY MAKE GAS FLOW RATE (SCFM)                17.5       18.5

 HEATING VALUE OF SWEET GAS (BTU/SCF)        212.7      217.5

 EFFLUENT FLOW RATES (LB/HR)
          CO                                 15.61      15.49
          H2                                  1.22       1.36
          CH4                                 0.54       0.57
          CO2                                17.45      22.09
          N2                                 36.74      36.72
          H2S                                 0.545      0.421
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                GO-47  2/14/80  12:00-16:00


      REACTOR SPECIFICATIONS                         FEED RATES AND RATIOS

PRESSURE     = 104.2 PSIG ( 819.4 KPA)          COAL      = 36.10 LB/HR (16.37 KG/HR)
TEMPERATURE  = 1814.6 DEG.F ( 990.3 DEG.C)      STEAM     = 37.28 LB/HR (16.91 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN    = 12.83 LB/HR ( 5.82 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  = 24.53 LB/HR (11.13 KG/HR)
ESTIMATED BED VOIDAGE = 0.75                    PURGE N2  = 12.15 LB/HR ( 5.51 KG/HR)
SOLIDS HOLDUP = 17.3 LB ( 7.8 KG)               STEAM/CARBON = 0.82 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.16 MOLES O2/MOLE C
                                                N2/O2        = 2.18 MOLES N2/MOLE O2


               ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                MASS     C       H       O       N       S

         COAL   36.1   30.21   0.23    1.01    0.08   0.966
        GASES   86.8    0.00   4.17   45.93   36.67   0.000
  TOTAL INPUT  122.9   30.21   4.40   46.95   36.75   0.966

         CHAR   18.8   15.23   0.04    0.34    0.04   0.363
         DUST    1.5    1.23   0.01    0.05    0.00   0.023
        GASES   98.8   12.96   4.16   44.48   36.71   0.526
   WASTEWATER    0.0    0.00   0.00    0.00    0.00   0.000
 TOTAL OUTPUT  119.2   29.41   4.20   44.87   36.75   0.912

 % RECOVERY    97.0%   97.4%  95.6%   95.6%  100.0%  94.4%


                                      EXPERIMENTAL   MODEL

 CARBON CONVERSION (PERCENT)
    COMBUSTION                                        16.8
    GASIFICATION                                      26.4
    TOTAL                                 42.9        43.2

  DRY MAKE GAS FLOW RATE (SCFM)           18.4        18.5

  HEATING VALUE OF SWEET GAS (BTU/SCF)   216.9       213.8

  EFFLUENT FLOW RATES (LB/HR)
           CO                            17.03       15.36
           H2                             1.34        1.38
           CH4                            0.61        0.58
           CO2                           19.00       22.03
           N2                            36.71       36.68
           H2S                            0.530       0.439
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                          GO-48  2/26/80  11:00-15:30


        REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 103.8 PSIG ( 816.7 KPA)          COAL        = 34.51 LB/HR (15.65 KG/HR)
TEMPERATURE  = 1818.3 DEG.F ( 992.4 DEG.C)      STEAM       = 56.03 LB/HR (25.41 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN      = 13.79 LB/HR ( 6.26 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  =  6.88 LB/HR ( 3.12 KG/HR)
ESTIMATED BED VOIDAGE = 0.77                    PURGE N2  = 10.85 LB/HR ( 4.92 KG/HR)
SOLIDS HOLDUP = 16.3 LB ( 7.4 KG)               STEAM/CARBON = 1.33 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.18 MOLES O2/MOLE C
                                                N2/O2        = 0.57 MOLES N2/MOLE O2


                  ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                    MASS      C       H       O       N       S

          COAL      34.5   28.07    0.19    1.30    0.17   0.930
         GASES      87.6    0.00    6.27   63.55   17.73   0.000
   TOTAL INPUT     122.1   28.07    6.46   64.84   17.90   0.930

          CHAR      15.9   12.54    0.06    0.45    0.03   0.267
          DUST       2.1    1.61    0.01    0.07    0.00   0.026
         GASES     106.8   15.21    6.69   66.34   17.87   0.632
    WASTEWATER       0.0    0.00    0.00    0.00    0.00   0.000
  TOTAL OUTPUT     124.7   29.36    6.76   66.87   17.91   0.925

  % RECOVERY      102.2%  104.6%  104.6%  103.1%  100.0%   99.4%



                                              EXPERIMENTAL   MODEL

  CARBON CONVERSION (PERCENT)
     COMBUSTION                                               19.4
     GASIFICATION                                             34.1
     TOTAL                                        54.2        53.5

   DRY MAKE GAS FLOW RATE (SCFM)                  16.4        16.5

   HEATING VALUE OF SWEET GAS (BTU/SCF)          315.5       311.7

   EFFLUENT FLOW RATES (LB/HR)
            CO                                   18.44       16.83
            H2                                    1.63        1.72
            CH4                                   0.89        0.73
            CO2                                  24.28       26.60
            N2                                   17.87       17.81
            H2S                                   0.643       0.507
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                         RUN GO-49  3/13/80  11:00-16:30


        REACTOR SPECIFICATIONS                            FEED RATES AND RATIOS

  PRESSURE     =  78.4 PSIG ( 641.6 KPA)              COAL      = 36.72 LB/HR (16.66 KG/HR)
  TEMPERATURE  = 1818.3 DEG.F ( 992.4 DEG.C)          STEAM     = 37.09 LB/HR (16.82 KG/HR)
  BED HEIGHT   = 38.0 IN. (0.97 METERS)               OXYGEN    = 13.15 LB/HR ( 5.97 KG/HR)
  BED DIAMETER =  6.0 IN. (0.152 METERS)              NITROGEN  =  6.79 LB/HR ( 3.08 KG/HR)
  ESTIMATED BED VOIDAGE = 0.78                        PURGE N2  = 10.44 LB/HR ( 4.74 KG/HR)
  SOLIDS HOLDUP = 15.1 LB ( 6.8 KG)                   STEAM/CARBON = 0.83 MOLES STEAM/MOLE C
                                                      O2/CARBON    = 0.17 MOLES O2/MOLE C
                                                      N2/O2        = 0.59 MOLES N2/MOLE O2


                       ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                       MASS      C       H       O       N       S

              COAL     36.7    29.85    0.17    1.39    0.18   1.042
             GASES     67.5     0.00    4.15   46.09   17.23   0.000
       TOTAL INPUT    104.2    29.85    4.32   47.48   17.41   1.042

              CHAR     22.2    14.58    0.06    0.22    0.07   0.377
              DUST      1.8     1.47    0.01    0.06    0.01   0.028
             GASES     83.5    13.90    3.76   47.98   17.33   0.546
        WASTEWATER      0.0     0.00    0.00    0.00    0.00   0.000
      TOTAL OUTPUT    107.5    29.95    3.83   48.26   17.41   0.950

      % RECOVERY     103.2%   100.3%   88.6%  101.6%  100.0%   91.2%



                                             EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
        COMBUSTION                                            17.4
        GASIFICATION                                          25.9
        TOTAL                                    46.6         43.3

       DRY MAKE GAS FLOW RATE (SCFM)             13.7         14.1

       HEATING VALUE OF SWEET GAS (BTU/SCF)     294.1        300.3

       EFFLUENT FLOW RATES (LB/HR)
                   CO                            15.47        15.08
                   H2                             0.99         1.31
                   CH4                            0.49         0.53
                   CO2                           25.26        22.23
                   N2                            17.33        17.30
                   H2S                            0.549        0.457
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                          GO-51  4/3/80  12:00-16:30


          REACTOR SPECIFICATIONS                            FEED RATES AND RATIOS

   PRESSURE      =  78.2 PSIG ( 640.6 KPA)            COAL       = 37.00 LB/HR (16.78 KG/HR)
   TEMPERATURE  = 1815.3 DEG.F ( 990.7 DEG.C)         STEAM      = 37.65 LB/HR (17.08 KG/HR)
   BED HEIGHT    = 38.0 IN. (0.97 METERS)              OXYGEN     = 11.33 LB/HR ( 5.14 KG/HR)
   BED DIAMETER =  6.0 IN. (0.152 METERS)             NITROGEN  =  6.46 LB/HR ( 2.93 KG/HR)
   ESTIMATED BED VOIDAGE = 0.76                        PURGE N2  =  5.84 LB/HR ( 2.65 KG/HR)
   SOLIDS HOLDUP = 16.7 LB ( 7.6 KG)                   STEAM/CARBON = 0.83 MOLES STEAM/MOLE C
                                                       O2/CARBON    = 0.14 MOLES O2/MOLE C
                                                       N2/O2        = 0.65 MOLES N2/MOLE O2


                          ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                           MASS      C        H        O        N        S

                 COAL      37.0    30.40     0.22     1.25     0.18    0.991
                 GASES     61.3     0.00     4.21    44.77    12.30    0.000
           TOTAL INPUT     98.3    30.40     4.44    46.02    12.49    0.991

                 CHAR      21.6    16.82     0.08     0.57     0.11    0.458
                 DUST       1.9     1.29     0.01     0.21     0.02    0.033
                 GASES     78.9    12.13     4.73    49.17    12.37    0.489
            WASTEWATER      0.0     0.00     0.00     0.00     0.00    0.000
          TOTAL OUTPUT    102.3    30.23     4.81    49.95    12.49    0.979

          % RECOVERY     104.1%    99.5%   108.4%   108.5%   100.1%    98.8%



                                                   EXPERIMENTAL   MODEL

          CARBON CONVERSION (PERCENT)
             COMBUSTION                                               14.7
             GASIFICATION                                             26.3
             TOTAL                                     39.9           41.0

           DRY MAKE GAS FLOW RATE (SCFM)               13.1           13.1

           HEATING VALUE OF SWEET GAS (BTU/SCF)       304.8          305.2

           EFFLUENT FLOW RATES (LB/HR)
                       CO                              11.42          15.01
                       H2                               1.43           1.39
                       CH4                              0.64           0.57
                       CO2                             24.71          20.53
                       N2                              12.37          12.36
                       H2S                              0.497          0.423
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                      GO-53  4-17-80  12:00-16:30    (FEED SCREW PROBLEMS)


                                                      FEED RATES AND RATIOS
          REACTOR SPECIFICATIONS
                                              COAL       = 48.06 LB/HR (21.80 KG/HR)
 PRESSURE     = 104.2 PSIG ( 819.4 KPA)       STEAM      = 56.03 LB/HR (25.41 KG/HR)
 TEMPERATURE  = 1818.7 DEG.F ( 992.6 DEG.C)   OXYGEN     = 15.08 LB/HR ( 6.84 KG/HR)
 BED HEIGHT   = 38.0 IN. (0.97 METERS)        NITROGEN   =  4.96 LB/HR ( 2.25 KG/HR)
 BED DIAMETER =  6.0 IN. (0.152 METERS)       PURGE N2   = 11.85 LB/HR ( 5.37 KG/HR)
 ESTIMATED BED VOIDAGE = 0.76                 STEAM/CARBON = 0.98 MOLES STEAM/MOLE C
 SOLIDS HOLDUP = 16.7 LB ( 7.6 KG)            O2/CARBON    = 0.15 MOLES O2/MOLE C
                                              N2/O2        = 0.38 MOLES N2/MOLE O2


                 ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                  MASS      C        H        O        N        S

          COAL    48.1    37.98     0.25     2.78     0.24    1.414
         GASES    87.9     0.00     6.27    64.83    16.81    0.000
   TOTAL INPUT   136.0    37.98     6.52    67.61    17.05    1.414

          CHAR    25.1    17.88     0.10     1.78     0.25    0.467
          DUST     2.5     1.85     0.01     0.22     0.02    0.037
         GASES   110.1    15.30     7.68    69.47    16.79    0.864
    WASTEWATER     0.0     0.00     0.00     0.00     0.00    0.000
  TOTAL OUTPUT   137.7    35.03     7.79    71.46    17.06    1.369

  % RECOVERY     101.3%   92.2%   119.5%   105.7%   100.1%    96.8%



                                              EXPERIMENTAL   MODEL

  CARBON CONVERSION (PERCENT)
     COMBUSTION                                               15.7
     GASIFICATION                                             28.0
     TOTAL                                        40.3        43.7

   DRY MAKE GAS FLOW RATE (SCFM)                  18.9        17.4

   HEATING VALUE OF SWEET GAS (BTU/SCF)          335.8       327.0

   EFFLUENT FLOW RATES (LB/HR)
            CO                                   13.30       18.99
            H2                                    2.51        1.82
            CH4                                   1.08        0.79
            CO2                                  32.16       28.71
            N2                                   16.79       16.90
            H2S                                   0.881       0.619
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                      *
                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         GO-54  5-13-80  11:30-15:00


        REACTOR SPECIFICATIONS                            FEED RATES AND RATIOS

PRESSURE     = 106.4 PSIG ( 835.3 KPA)              COAL       = 64.91 LB/HR (29.44 KG/HR)
TEMPERATURE  = 1800.8 DEG.F ( 982.7 DEG.C)          STEAM      = 67.06 LB/HR (30.42 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)               OXYGEN     = 20.53 LB/HR ( 9.31 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)              NITROGEN   =  4.68 LB/HR ( 2.12 KG/HR)
ESTIMATED BED VOIDAGE = 0.76                        PURGE N2   = 15.17 LB/HR ( 6.88 KG/HR)
SOLIDS HOLDUP = 16.8 LB ( 7.6 KG)                   STEAM/CARBON = 0.87 MOLES STEAM/MOLE C
                                                    O2/CARBON    = 0.15 MOLES O2/MOLE C
                                                    N2/O2        = 0.26 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C       H       O       N       S

            COAL      64.9    51.29    0.34    3.76    0.32   1.753
           GASES     107.4     0.00    7.50   80.08   19.85   0.000
     TOTAL INPUT     172.3    51.29    7.84   83.83   20.17   1.753

            CHAR      30.0    21.34    0.12    2.12    0.30   0.571
            DUST      17.2    12.80    0.10    1.51    0.17   0.258
           GASES     122.8    18.20    7.31   76.61   19.70   0.945
      WASTEWATER       0.0     0.00    0.00    0.00    0.00   0.000
    TOTAL OUTPUT     170.0    52.34    7.52   80.24   20.17   1.774

    % RECOVERY       98.6%   102.0%   95.9%   95.7%  100.0%  101.2%



                                            EXPERIMENTAL   MODEL

    CARBON CONVERSION (PERCENT)
       COMBUSTION                                           15.8
       GASIFICATION                                         21.9
       TOTAL                                    35.5        37.7

     DRY MAKE GAS FLOW RATE (SCFM)              19.6        19.7

     HEATING VALUE OF SWEET GAS (BTU/SCF)      337.5       330.1

     EFFLUENT FLOW RATES (LB/HR)
             CO                                15.87       20.64
             H2                                 2.03        1.91
             CH4                                1.07        0.83
             CO2                               38.79       36.09
             N2                                19.70       19.96
             H2S                                0.969       0.675
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* NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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* FLUIDIZED BED COAL GASIFICATION REACTOR *
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                GD-55  5-22-80  10:30-12:00


      REACTOR SPECIFICATIONS                              FEED RATES AND RATIOS

PRESSURE     =  77.5 PSIG ( 635.5 KPA)               COAL        = 35.37 LB/HR (16.04 KG/HR)
TEMPERATURE  = 1738.8 DEG.F ( 948.2 DEG.C)           STEAM       = 45.53 LB/HR (20.65 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)                OXYGEN      = 10.21 LB/HR ( 4.63 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)               NITROGEN  =  4.54 LB/HR ( 2.06 KG/HR)
ESTIMATED BED VOIDAGE = 0.76                         PURGE N2  =  7.84 LB/HR ( 3.56 KG/HR)
SOLIDS HOLDUP = 16.5 LB ( 7.5 KG)                    STEAM/CARBON = 1.05 MOLES STEAM/MOLE C
                                                     O2/CARBON    = 0.13 MOLES O2/MOLE C
                                                     N2/O2        = 0.51 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                       MASS      C        H        O        N        S

             COAL      35.4    28.80     0.22     0.79     0.18    0.969
            GASES      68.1     0.00     5.09    50.64    12.38    0.000
      TOTAL INPUT     103.5    28.80     5.31    51.43    12.56    0.969

             CHAR      21.9    18.36     0.09     0.05     0.11    0.445
             DUST       1.9     1.51     0.00     0.09     0.02    0.031
            GASES      81.5    10.65     5.29    52.54    12.43    0.584
       WASTEWATER       0.0     0.00     0.00     0.00     0.00    0.000
     TOTAL OUTPUT     105.3    30.52     5.38    52.68    12.56    1.060

     % RECOVERY      101.8%   106.0%   101.2%   102.4%   100.0%   109.5%


                                             EXPERIMENTAL    MODEL

     CARBON CONVERSION (PERCENT)
        COMBUSTION                                            14.0
        GASIFICATION                                          19.8
        TOTAL                                    37.0         33.8

      DRY MAKE GAS FLOW RATE (SCFM)              11.7         10.8

      HEATING VALUE OF SWEET GAS (BTU/SCF)      315.3        307.3

      EFFLUENT FLOW RATES (LB/HR)
                 CO                             10.10         9.85
                 H2                              1.20         1.08
                 CH4                             0.57         0.43
                 CO2                            21.54        19.07
                 N2                             12.43        12.44
                 H2S                             0.590        0.334
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                         * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                         *                                         *
                         * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                                GD-56  5-27-80  11:00-18:00


          REACTOR SPECIFICATIONS                              FEED RATES AND RATIOS

PRESSURE      = 104.0 PSIG ( 818.3 KPA)              COAL        = 35.21 LB/HR (15.97 KG/HR)
TEMPERATURE   = 1825.1 DEG.F ( 996.2 DEG.C)          STEAM       = 66.54 LB/HR (30.18 KG/HR)
BED HEIGHT    = 38.0 IN. (0.97 METERS)               OXYGEN      = 14.91 LB/HR ( 6.77 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)               NITROGEN  =  4.35 LB/HR ( 1.97 KG/HR)
ESTIMATED BED VOIDAGE = 0.78                         PURGE N2  =  9.67 LB/HR ( 4.39 KG/HR)
SOLIDS HOLDUP = 15.3 LB ( 6.9 KG)                    STEAM/CARBON = 1.55 MOLES STEAM/MOLE C
                                                     O2/CARBON    = 0.20 MOLES O2/MOLE C
                                                     N2/O2        = 0.33 MOLES N2/MOLE O2


                            ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                             MASS      C        H        O        N        S

                 COAL        35.2    28.64     0.19     1.15     0.04    0.967
                GASES        95.5     0.00     7.44    74.00    14.02    0.000
          TOTAL INPUT       130.7    28.64     7.64    75.15    14.07    0.967

                 CHAR        14.2    10.83     0.04     0.03     0.01    0.238
                 DUST         2.2     1.73     0.01     0.03     0.00    0.026
                GASES       112.0    15.83     7.43    73.82    14.06    0.827
           WASTEWATER         0.0     0.00     0.00     0.00     0.00    0.000
         TOTAL OUTPUT       128.4    28.40     7.48    73.89    14.07    1.092

         % RECOVERY         98.2%    99.2%    97.9%    98.3%   100.0%   112.8%



                                                  EXPERIMENTAL   MODEL

         CARBON CONVERSION (PERCENT)
            COMBUSTION                                           20.6
            GASIFICATION                                         36.2
            TOTAL                                     55.3       56.8

          DRY MAKE GAS FLOW RATE (SCFM)               16.6       16.8

          HEATING VALUE OF SWEET GAS (BTU/SCF)       329.3      331.3

          EFFLUENT FLOW RATES (LB/HR)
                   CO                                16.28      18.04
                   H2                                 1.86       1.88
                   CH4                                0.73       0.79
                   CO2                               30.39      29.12
                   N2                                14.06      14.04
                   H2S                                0.841      0.562
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                         * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                         * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                                GO-57  6-5-80  12:30-14:30


        REACTOR SPECIFICATIONS                                 FEED RATES AND RATIOS

PRESSURE     = 104.1 PSIG ( 818.9 KPA)                 COAL      = 35.03 LB/HR (15.89 KG/HR)
TEMPERATURE  = 1825.5 DEG.F ( 996.4 DEG.C)             STEAM     = 56.17 LB/HR (25.48 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)                  OXYGEN    = 14.11 LB/HR ( 6.40 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)                 NITROGEN  =  4.87 LB/HR ( 2.21 KG/HR)
ESTIMATED BED VOIDAGE = 0.78                           PURGE N2  =  8.74 LB/HR ( 3.97 KG/HR)
SOLIDS HOLDUP = 15.6 LB ( 7.1 KG)                      STEAM/CARBON = 1.30 MOLES STEAM/MOLE C
                                                       O2/CARBON    = 0.18 MOLES O2/MOLE C
                                                       N2/O2        = 0.39 MOLES N2/MOLE O2


                             ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                              MASS      C       H       O       N       S

                    COAL      35.0   28.83    0.18    0.51    0.18   0.947
                   GASES      83.9    0.00    6.28   63.99   13.61   0.000
             TOTAL INPUT     118.9   28.83    6.47   64.50   13.79   0.947

                    CHAR      16.7   11.67    0.05    0.24    0.08   0.258
                    DUST       1.5    1.15    0.00    0.02    0.01   0.021
                   GASES      99.3   16.20    5.92   62.75   13.69   0.734
              WASTEWATER       0.0    0.00    0.00    0.00    0.00   0.000
            TOTAL OUTPUT     117.5   29.03    5.98   63.02   13.78   1.013

              % RECOVERY     98.8%  100.7%   92.5%   97.7%  100.0%  107.0%


                                                     EXPERIMENTAL   MODEL

              CARBON CONVERSION (PERCENT)
                 COMBUSTION                                          19.3
                 GASIFICATION                                        33.7
                 TOTAL                                   56.2        53.0

               DRY MAKE GAS FLOW RATE (SCFM)             16.2        15.9

               HEATING VALUE OF SWEET GAS (BTU/SCF)     333.3       326.0

               EFFLUENT FLOW RATES (LB/HR)
                         CO                             16.58       17.30
                         H2                              1.69        1.76
                         CH4                             1.04        0.76
                         CO2                            30.41       26.80
                         N2                             13.69       13.70
                         H2S                             0.745       0.527
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                         * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                         * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                                GO-58  6-17-80  11:00-14:20


        REACTOR SPECIFICATIONS                                 FEED RATES AND RATIOS

PRESSURE     = 102.6 PSIG ( 808.9 KPA)                 COAL      = 32.87 LB/HR (14.91 KG/HR)
TEMPERATURE  = 1814.3 DEG.F ( 990.1 DEG.C)             STEAM     = 44.03 LB/HR (19.97 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)                  OXYGEN    = 12.24 LB/HR ( 5.55 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)                 NITROGEN  =  5.52 LB/HR ( 2.51 KG/HR)
ESTIMATED BED VOIDAGE = 0.77                           PURGE N2  =  8.65 LB/HR ( 3.92 KG/HR)
SOLIDS HOLDUP = 16.3 LB ( 7.4 KG)                      STEAM/CARBON = 1.08 MOLES STEAM/MOLE C
                                                       O2/CARBON    = 0.17 MOLES O2/MOLE C
                                                       N2/O2        = 0.52 MOLES N2/MOLE O2


                             ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                              MASS     C       H       O       N       S

                      COAL     32.9   27.20    0.17    0.58    0.16   0.882
                     GASES     70.4    0.00    4.93   51.34   14.17   0.000
               TOTAL INPUT    103.3   27.20    5.10   51.92   14.34   0.882

                      CHAR     18.2   14.29    0.08    0.12    0.02   0.339
                      DUST      1.2    0.94    0.00    0.04    0.01   0.019
                     GASES     86.8   14.04    5.00   52.96   14.32   0.438
                WASTEWATER      0.0    0.00    0.00    0.00    0.00   0.000
              TOTAL OUTPUT    106.2   29.27    5.09   53.12   14.34   0.797

              % RECOVERY     102.8%  107.6%   99.8%  102.3%  100.0%   90.3%


                                                     EXPERIMENTAL   MODEL

              CARBON CONVERSION (PERCENT)
                 COMBUSTION                                             17.8
                 GASIFICATION                                           30.6
                 TOTAL                                   51.6           48.4

               DRY MAKE GAS FLOW RATE (SCFM)             15.0           14.1

               HEATING VALUE OF SWEET GAS (BTU/SCF)     321.9          315.5

               EFFLUENT FLOW RATES (LB/HR)
                         CO                             13.26          14.96
                         H2                              1.62           1.48
                         CH4                             0.87           0.65
                         CO2                            28.18          22.83
                         N2                             14.32          14.24
                         H2S                             0.435          0.450
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                       * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                       * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                           RUN GO-59  6-26-80  11:30-16:30


        REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

  PRESSURE     = 104.6 PSIG ( 822.8 KPA)          COAL      = 38.37 LB/HR (17.40 KG/HR)
  TEMPERATURE  = 1831.0 DEG.F ( 999.4 DEG.C)      STEAM     = 65.12 LB/HR (29.54 KG/HR)
  BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN    = 16.57 LB/HR ( 7.52 KG/HR)
  BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN  =  3.04 LB/HR ( 1.38 KG/HR)
  ESTIMATED BED VOIDAGE = 0.78                    PURGE N2  = 10.07 LB/HR ( 4.57 KG/HR)
  SOLIDS HOLDUP = 15.6 LB ( 7.1 KG)               STEAM/CARBON = 1.37 MOLES STEAM/MOLE C
                                                  O2/CARBON    = 0.20 MOLES O2/MOLE C
                                                  N2/O2        = 0.21 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                        MASS      C       H       O       N       S

              COAL      38.4    31.62    0.18    0.97    0.19   1.055
              GASES     94.8     0.00    7.29   74.40   13.11   0.000
        TOTAL INPUT    133.2    31.62    7.46   75.37   13.31   1.055

              CHAR      17.2    13.26    0.05    0.12    0.09   0.283
              DUST       2.3     1.87    0.01    0.04    0.01   0.031
             GASES     111.5    16.46    7.22   73.85   13.21   0.781
        WASTEWATER       0.0     0.00    0.00    0.00    0.00   0.000
      TOTAL OUTPUT     131.1    31.59    7.28   74.00   13.31   1.096

      % RECOVERY       98.4%    99.9%   97.6%   98.2%  100.0%  103.8%


                                             EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
        COMBUSTION                                            20.7
        GASIFICATION                                          34.5
        TOTAL                                    52.1         55.2

       DRY MAKE GAS FLOW RATE (SCFM)             16.7         17.4

       HEATING VALUE OF SWEET GAS (BTU/SCF)     344.5        341.0

       EFFLUENT FLOW RATES (LB/HR)
                   CO                           15.00        19.57
                   H2                            1.84         1.95
                   CH4                           0.96         0.84
                   CO2                          34.10        30.97
                   N2                           13.21        13.21
                   H2S                           0.801        0.617
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
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                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                          RUN GO-60  7-18-80  11:00-16:30


       REACTOR SPECIFICATIONS                          FEED RATES AND RATIOS

PRESSURE     = 103.4 PSIG ( 814.2 KPA)          COAL       = 47.33 LB/HR (21.47 KG/HR)
TEMPERATURE  = 1817.6 DEG.F ( 992.0 DEG.C)      STEAM      = 48.32 LB/HR (21.92 KG/HR)
BED HEIGHT   = 38.0 IN. (0.97 METERS)           OXYGEN     = 13.20 LB/HR ( 5.99 KG/HR)
BED DIAMETER =  6.0 IN. (0.152 METERS)          NITROGEN   = 13.57 LB/HR ( 6.16 KG/HR)
ESTIMATED BED VOIDAGE = 0.75                    PURGE N2   =  8.48 LB/HR ( 3.84 KG/HR)
SOLIDS HOLDUP = 17.5 LB ( 8.0 KG)               STEAM/CARBON = 0.83 MOLES STEAM/MOLE C
                                                O2/CARBON    = 0.13 MOLES O2/MOLE C
                                                N2/O2        = 1.17 MOLES N2/MOLE O2


                    ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                     MASS     C       H       O       N       S

              COAL   47.3   38.74    0.32    1.22    0.24   1.270
             GASES   83.6    0.00    5.41   56.11   22.05   0.000
       TOTAL INPUT  130.9   38.74    5.73   57.33   22.29   1.270

              CHAR   35.5   22.64    0.14    1.95    0.18   0.728
              DUST    2.4    1.84    0.02    0.15    0.01   0.033
             GASES   95.2   11.83    5.76   54.69   22.10   0.776
        WASTEWATER    0.0    0.00    0.00    0.00    0.00   0.000
      TOTAL OUTPUT  133.1   36.31    5.93   56.79   22.29   1.537

      % RECOVERY    101.7%   93.7%  103.5%   99.1%  100.0%  121.0%



                                             EXPERIMENTAL   MODEL

      CARBON CONVERSION (PERCENT)
         COMBUSTION                                          13.5
         GASIFICATION                                        25.3
         TOTAL                                    30.5       38.8

       DRY MAKE GAS FLOW RATE (SCFM)              15.8       17.5

       HEATING VALUE OF SWEET GAS (BTU/SCF)      261.5      276.3

       EFFLUENT FLOW RATES (LB/HR)
                   CO                            11.85      17.89
                   H2                             1.68       1.75
                   CH4                            0.54       0.75
                   CO2                           23.21      24.81
                   N2                            22.10      22.12
                   H2S                            0.795      0.511
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                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                        *
                    * FLUIDIZED BED COAL GASIFICATION REACTOR *
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                         RUN GO-61  7-25-80  11:30-16:15


          REACTOR SPECIFICATIONS                              FEED RATES AND RATIOS

  PRESSURE     = 104.5 PSIG ( 821.7 KPA)              COAL       = 36.40 LB/HR (16.51 KG/HR)
  TEMPERATURE  = 1847.9 DEG.F (1008.8 DEG.C)          STEAM      = 64.97 LB/HR (29.47 KG/HR)
  BED HEIGHT   = 38.0 IN. (0.97 METERS)               OXYGEN     = 15.08 LB/HR ( 6.84 KG/HR)
  BED DIAMETER =  6.0 IN. (0.152 METERS)              NITROGEN   =  3.70 LB/HR ( 1.68 KG/HR)
  ESTIMATED BED VOIDAGE = 0.76                        PURGE N2   = 11.43 LB/HR ( 5.18 KG/HR)
  SOLIDS HOLDUP = 16.9 LB ( 7.6 KG)                   STEAM/CARBON = 1.49 MOLES STEAM/MOLE C
                                                      O2/CARBON    = 0.19 MOLES O2/MOLE C
                                                      N2/O2        = 0.28 MOLES N2/MOLE O2


                      ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS      C       H       O       N       S

             COAL     36.4    29.14    0.20    1.92    0.18   0.935
            GASES     95.2     0.00    7.27   72.77   15.13   0.000
      TOTAL INPUT    131.6    29.14    7.47   74.69   15.31   0.935

             CHAR     17.8    11.89    0.08    0.79    0.09   0.292
             DUST      2.3     1.44    0.01    0.46    0.01   0.028
            GASES    106.8    13.60    7.33   69.87   15.21   0.753
       WASTEWATER      0.0     0.00    0.00    0.00    0.00   0.000
     TOTAL OUTPUT    126.9    26.94    7.42   71.13   15.31   1.073

     % RECOVERY      96.4%    92.5%   99.3%   95.2%  100.0%  114.8%



                                                 EXPERIMENTAL   MODEL

     CARBON CONVERSION (PERCENT)
       COMBUSTION                                                20.4
       GASIFICATION                                              40.2
       TOTAL                                          46.7       60.6

      DRY MAKE GAS FLOW RATE (SCFM)                   15.8       18.3

      HEATING VALUE OF SWEET GAS (BTU/SCF)           325.9      337.5

      EFFLUENT FLOW RATES (LB/HR)
              CO                                     12.91      20.48
              H2                                      1.88       2.06
              CH4                                     0.48       0.87
              CO2                                    28.20      30.20
              N2                                     15.21      15.23
              H2S                                     0.771      0.588
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APPENDIX B

APPENDIX B. DOCUMENTATION FOR DATA ANALYSIS PROGRAM

REQUIRED INPUT

The following input data is required by the data analysis program:

Card 1

Columns	Parameter	Significance
2-80	ALAB	Comment card. (run number,date, etc)

Card 2

Columns	Parameter	Significance
2-40	ALABC	Feed coal type and mesh size

Card 3

Columns	Parameter	Significance
1	ISIM	=1 to log only, =2 to simulate only, =3 to log and simulate, =4 to estimate feed for given output
9-16	PRES	Reactor pressure, psig
17-24	HT	Bed height, inches
25-32	DIAM	Bed diameter, inches
33-40	RLEAK	Estimated leak rate, SCFM
41-48	PDEN	Feed coal density, lb/ft^3
49-56	PBULK	Packed density of fixed bed, lb/ft^3

Card 4

Columns	Parameter	Significance
1-5	IHB(1)	Level of 1st (lowest) thermocouple, inches above feed gas inlet
6-10	IHB(2)	2nd
11-15	IHB(3)	3rd
16-20	IHB(4)	4th
21-25	IHB(5)	5th
26-30	IHB(6)	6th

Card 5

Columns	Parameter	Significance
1-8	TRP(1)	Temp. at 1st (lowest) point, F
9-16	TRP(2)	2nd
17-24	TRP(3)	3rd
25-32	TRP(4)	4th
33-40	TRP(5)	5th
41-48	TRP(6)	6th
49-56	TRP(7)	Temp. at gasifier exit, F

Card 6

Columns	Parameter	Significance
1-8	XMAR	Feed coal: mass fraction as-received moisture fraction
9-16	XMOIS	prox. analysis moisture fraction
17-24	XASH	prox. analysis ash fraction
25-32	XVOLA	prox. analysis vol. matter fraction
33-40	XULT(1)	ult. analysis C fraction
41-48	XULT(2)	ult. analysis H fraction
49-56	XULT(3)	ult. analysis N fraction
57-64	XULT(4)	ult. analysis S fraction

Card 7

Columns	Parameter	Significance
1-8	QINC	Feed rate of coal, lb/hr
9-16	QINH2O	Feed rate of steam, lb/hr
17-24	QINO2	Feed rate of oxygen, SCFM
25-32	QINN2	Feed rate of nitrogen, SCFM
33-40	TINC	Inlet temp. of coal feed, F
41-48	TIN	Inlet temp. of feed gases, F

Card 8

Columns	Parameter	Significance
1-8	IEXH	=1 for routine analysis, =2 for exhaustive analysis
9-16	AMCF	Mass of coal fed, lb
17-24	AMCH	Mass of char collected, lb
25-32	AMCYC	Mass of cyclone dust collected, lb
33-40	QCHAR	Char removal rate, lb/hr
41-48	DELTAP	Pressure drop over 20", in. H_2O
49-56	QPCSV	PCS outlet gas flow rate, SCFM
57-64	TPCS	PCS gas flowmeter temp., F
65-72	PPCS	PCS gas flowmeter pressure, psig
73-78	QSTV	Sample train flow rate, SCFM
79	MWFC	=1 for PCS gas flow rate measured by orifice meter, =0 otherwise

Card 9

Columns	Parameter	Significance
1-8	QPURN2	Purge nitrogen feed rate, SCFH
9-16	TINPN2	Purge N_2 flowmeter temp., F
17-24	PINPN2	Purge N_2 flowmeter pressure, psig
25-32	TINH2O	Steam flowmeter temp., F
33-40	PINH2O	Steam flowmeter pressure, psig
41-48	TINO2	Oxygen flowmeter temp., F
49-56	PINO2	Oxygen flowmeter pressure, psig
57-64	TINN2	Nitrogen flowmeter temp., F
65-72	PINN2	Nitrogen flowmeter pressure, psig

Card 10

Columns	Parameter	Significance
1-8	TCH2O	Steam flowmeter calibration temp., F
9-16	PCH2O	Steam flowmeter calibration pressure, psig
17-24	TCO2	Oxygen flowmeter cal. temp., F
25-32	PCO2	Oxygen flowmeter cal. pressure, psig
33-40	TCN2	Nitrogen flowmeter cal. temp., F
41-48	PCN2	Nitrogen flowmeter cal. pressure, psig
49-56	TCPN2	Purge N_2 flowmeter cal. temp., F
57-64	PCPN2	Purge N_2 flowmeter cal. pressure, psig
65-72	TCPCS	PCS gas flowmeter cal. temp., F
73-80	PCPCS	PCS gas flowmeter cal. pressure, psig

Card 11

Columns	Parameter	Significance
1-8	ACYC(1)	Percent (dry) O_2 in cyclone exit gas
9-16	ACYC(2)	" CO "
17-24	ACYC(3)	" H_2 "
25-32	ACYC(4)	" CH_4 "
33-40	ACYC(5)	" CO_2 "
41-48	ACYC(6)	" N_2 "
49-56	ACYC(7)	" H_2S "
57-64	ACYC(8)	" COS "
65-72	ACYC(9)	Percent (wet) H_2O in cyclone exit gas

Card 12

Columns	Parameter	Significance
1-8	APCS(1)	Percent (dry) O_2 in PCS exit gas
9-16	APCS(2)	" CO "
17-24	APCS(3)	" H_2 "
25-32	APCS(4)	" CH_4 "
33-40	APCS(5)	" CO_2 "
41-48	APCS(6)	" N_2 "
49-56	APCS(7)	" H_2S "
57-64	APCS(8)	" COS "

Card 13

Columns	Parameter	Significance
1-8	XMARCH	Spent char: mass fraction as-received moisture
9-16	XMCH	prox. analysis moisture fraction
17-24	XASHCH	prox. analysis ash fraction
25-32	XVOLCH	prox. analysis vol. matter
33-40	XUCH(1)	ult. analysis C fraction
41-48	XUCH(2)	ult. analysis H fraction
49-56	XUCH(3)	ult. analysis N fraction
57-64	XUCH(4)	ult. analysis S fraction

Card 14

Columns	Parameter	Significance
1-8	XMARCY	Cyc. dust: mass fraction as-received moisture
9-16	XMCY	prox. analysis moisture fraction
17-24	XASHCY	prox. analysis ash fraction
25-32	XVOLCY	prox. analysis vol. matter
33-40	XUCY(1)	ult. analysis C fraction
41-48	XUCY(2)	ult. analysis H fraction
49-56	XUCY(3)	ult. analysis N fraction
57-64	XUCY(4)	ult. analysis S fraction

Card 15

Columns	Parameter	Significance
1-8	QSCRUB	% scrubber pump capacity
9-16	DPT232	Venturi pressure drop, in. H_2O
17-24	TT234	Venturi exit temperature, F
25-32	PCSWT	PCS tank temperature, F
33-40	PCSWL	PCS tank water level, inches

Card 16

Columns	Parameter	Significance
1-8	XDP(1)	Fraction of feed coal on 1st sieve
9-16	XDP(2)	" 2nd sieve
17-24	XDP(3)	" 3rd sieve
25-32	XDP(4)	" 4th sieve
33-40	XDP(5)	" 5th sieve
41-48	XDP(6)	" 6th sieve
49-56	XDP(7)	" 7th sieve
57-64	XDP(8)	" 8th sieve
65-72	XDP(9)	" 9th sieve

Card 17

Columns	Parameter	Significance
1-10	PH	pH of sample trap water
11-20	NTW	Number of species analyzed in trap water (end in column 20)
21-30	NT	Number of trace elements analyzed (end in column 30)

If NTW=0, go directly to Card 19. Otherwise, include as many of Cards 18 as are needed.

Card 18 (Trap water analysis)

Columns	Parameter	Significance
1-4	SPW(1)	Symbol for 1st species (limit of 4 characters)
10-18	CWATR(1)	Concentration of 1st species, milligrams/liter
21-24	SPW(2)	Symbol for 2nd species
30-38	CWATR(2)	Concentration of 2nd species
41-44	SPW(3)	Symbol
50-58	CWATR(3)	Concentration
61-64	SPW(4)	Symbol
70-78	CWATR(4)	Concentration

If NT=0, omit Card 19. Otherwise, include as many of Cards 19 as are needed.

Card 19 (Trace element analysis)

Columns	Parameter	Significance
1-2	TNAM	Symbol of trace element
11-20	CMW	Molecular weight of element
21-30	CTC	Concentration in feed coal, micrograms/gram
31-40	CTCH	Concentration in spent char
41-50	CTCYD	Concentration in cyclone dust
51-60	CTW	Concentration in trap water

Repeat Cards 1-19 for each run to be analyzed.

EXAMPLE

The input for a representative run is given in Table B-1. The resulting program output is shown in Figures B-1 through B-6.

DESCRIPTION OF CALCULATIONS

The calculations performed by the program and the variables printed are reviewed below. (see Figures B-1 through B-6).

Reactor Specifications

The bed pressure and the bed height and diameter are printed as read in. The average bed temperature printed is the volume-weighted average of the bed temperature profile.

The apparent bed density, d_a ,is calculated by assuming that the pressure drop measured over a 20 inch length of the bed is due to a 20 inch static head (i .e ., frictional losses are neglected), and the density of the gas in the bed, d_g , is calculated by the ideal gas law. An average molecular weight equal to that of the cyclone exit gas is assumed. If d_s is the density of the solid particles, then the void fraction in the bed ("estimated bed voidage") is

$$e = (d_s - d_s)/(d_s - d_s) \qquad (1)$$

The density of solids in the fluidized bed is

$$d_{ba} = d_s (1 - e) \qquad (2)$$

The bed expansion factor, or the ratio of the expanded bed volume to the settled bed volume is given by

$$BEF = d_b / d_{ba} \qquad (3)$$

where d_b is the settled bed density (an input parameter).

The input value of the estimated system leak rate is printed. The leak rate is calculated from the results of a static pressure test performed prior to every run.

Solid Feed Properties

The coal type, pretreatment temperature, solid particle and settled bed densities, and as-received moisture content of the solid feed are printed out as read in.

The average particle diameter is calculated from the read-in sieve analysis.

Proximate Analysis and Ultimate Analysis of Solids

The proximate analysis of the coal feed, which consists of the mass fractions of moisture, volatile matter, ash, and fixed carbon (determined by difference), is printed out as read in. The ultimate analysis, consisting of the mass fractions of C, H, O (determined by difference), N, S, and ash is printed out for the coal feed, spent char, and cyclone dust after being converted from the as-determined basis to the as-received basis.

Feed Rates

The feed rate and estimated feed temperature of the solid feed are printed out as read in, as are the feed rates of steam, oxygen and nitrogen. The purge nitrogen flow rate must be corrected for the dependence of the rotameter reading on the square root of the gas density. The corrected flow rate is

$$Q = Q_o(T_cP_m/T_mP_c)^{0.5} \tag{4}$$

Feed Ratios and Conditions

The feed rate of coal on a moisture and ash free basis is

$$Q_{maf} = Q_s (1 - x_{mois} - x_{ash}) \tag{5}$$

where Q_s is the coal feed rate, and x_{mois} and x_{ash} are the mass fractions of moisture and ash determined by proximate analysis. The feed rate of carbon is calculated as

$$Q_{car} = Q_s x_c \tag{6}$$

where x_c is the mass fraction of carbon determined by ultimate analysis. The ratios of the feed rates of steam and oxygen to both Q_{maf} and Q_{car} are calculated and printed out. The mole ratio of nitrogen (not counting purge nitrogen) to oxygen in the feed is calculated from the feed rates of N_2 and O_2. The combined gas feed temperature is printed out as read in.

The superficial gas velocity is calculated by adding the molar feed rates of steam, O_2, and N_2 (not counting purge nitrogen), converting to an equivalent volumetric flow rate at the reactor temperature and pressure assuming ideal gas behavior, and dividing the result by the reactor cross-sectional area.

Control Variables

The reactor temperature and N_2/O_2 feed ratio are reprinted. The steam partial pressure at the reactor inlet is calculated by multiplying the mole fraction of steam in the feed gas (steam + O_2 + N_2) times the absolute reactor pressure. The bed height is printed as read in.

The solid holdup in the reactor is calculated as

$$M_s = d_{ba}\ h\ A \tag{7}$$

where d_{ba} is the bulk solid density calculated by Eq . (B2), h is the bed height, and A is the bed cross-sectional area. The solid space time is then calculated as

$$t_s = M_s/Q_s \tag{8}$$

where again Q_s is the coal feed rate.

The gas space time is

$$t_g = h/v_s \tag{9}$$

where h is the bed height and v_s is the superficial gas velocity.

Output Variables

The pressure drop over 20 inches of the bed is printed out as read in. The measured PCS exit gas flow rate is corrected for the difference between the PCS gas density and the density of the calibration gas (N_2), as the orifice meter reading has a square root dependency on the gas density. Assuming ideal gas behavior, the corrected flow rate is

$$Q_{pcs} = Q'_{pcs}(M_c/M_{pcs})^{0.5} \tag{10}$$

where Q'_{pcs} is the measured flow rate, M_c is the calibration gas molecular weight, and M_{pcs} is the average molecular weight of the PCS gas. For runs where the PCS exit gas flow rate is measured with a Roots rotary positive displacement gas meter, no density correction is needed and the correction is bypassed. The leak rate and the sample train flow rate are added, and the corrected value is printed out.

The PCS exit gas chromatographic analysis does not include water. It is assumed that the sample is saturated at the flowmeter temperature T_m and pressure P_m. The vapor pressure of water is calculated from the Antoine equation

$$\log_{10} p^* = 8.10765 - 1750.286/(235.0+T_m) \tag{11}$$

The mole fraction of water in the gas is

$$y_w = p^*/P_m \tag{12}$$

The flow rate of the gas on a dry basis,

$$Q_{dry} = Q_{pcs}\ (1 - y_w) \tag{13}$$

It is presumed that the flow rate of dry gas at the cyclone exit equals that at the PCS system exit. The total flow rate at the cyclone exit is therefore

$$Q_{cyc} = Q_{dry}/(1 - y_w) \tag{14}$$

where y_{wc} is the measured mole fraction of water in the cyclone exit gas. Q_{cyc} is calculated from Eq. (B14) and printed, and the value of Q_{dry} is printed again. Finally, the solid holdup calculated by Eq. (B7) is printed.

Product Fuel Properties

The mole fractions of CO, H_2 and CH_4 in the cyclone exit gas are printed, along with ratios of the molar flow rates of these species to the feed rate of coal on a moisture and ash free basis [calculated by Eq . (B5)]. The percentages are based on the total gas, excluding water and effluent purge nitrogen.

The heating value of the product gas is calculated as follows. The flow rate of make gas is first calculated by summing the flow rates of the principal components other than water (CO, H_2, CH_4, CO_2, N_2, H_2S, and COS), and subtracting the feed rate of purge nitrogen. The flow rate of sweet gas is calculated by summing the flow rates of CO, H_2, CH_4, and N_2, and subtracting the purge nitrogen feed rate. The gross heating values of the make gas and sweet gas are determined by dividing the quantity

$$1.218\text{x}10^5 q_{CO} + 1.230\text{x}10^5 q_{HO} + 3.831\text{x}10^5 q_{CH4} \tag{15}$$

by the calculated flow rates of the gases. In Eq . (B15), q denotes the component flow rate in lbmoles/hr, and the coefficients are the gross heating values (Btu/lbmole) of CO, H_2, and CH_4, respectively.

Conversion Variables

Carbon conversion is calculated as

$$f_C = [(q_{CO}+q_{CO2}+q_{CH4}+q_{COS})(12.01)/(Q_s x_c)](100\%) \quad (16)$$

In Eq. (B16), the numerator represents the mass flow rate of atomic carbon in the gaseous reactor products, and the denominator is the rate at which atomic carbon enters the reactor in the solid feed (x_C is the mass fraction of carbon in the coal feed as determined by ultimate analysis).

The rate of steam consumption in the reactor is calculated as the rate at which water enters the reactor as steam and as-received moisture in the solid feed, minus the rate at which it leaves in the cyclone exit gas and as as-received moisture in the spent char and cyclone dust. (The small quantities of bound water in the solids are neglected.) The percentage steam conversion is calculated as

$$f_{H2O} = [\frac{(\text{rate of steam consumption})}{(\text{steam feed rate})}](100\%) \quad (17)$$

Finally, sulfur conversion is calculated as

$$f_s = [(q_{H2S}+q_{COS})(32.06)/(Q_s x_S)](100\%) \quad (18)$$

The definitions of the terms of this equation parallel those of Eq. (B16).

Solid Material Balance

The total amount of coal fed over the entire period of the run (the total loaded into the feed hopper minus the amount vacuumed out following the run) is printed out as read in. The masses of spent char and cyclone dust collected are printed out as read in, and as percentages of the total feed. The quantity of the solid feed that is gasified is calculated by difference and printed out. The average rate of char removal is printed as read in.

The average cyclone dust collection rate is

$$Q_{cyc} = Q_{ch} \cdot \left[\frac{\text{mass of cyclone dust collected}}{\text{mass of spent char collected}}\right] \quad (19)$$

where Q_{ch} is the spent char removal rate. It is assumed that the rate calculated by Eq . (B19) is applicable to the steady-state periods of operation of the reactor. Finally, the char removal rate that would give a zero error for the total mass balance is printed.

Cyclone Exit and PCS Exit Gas Analyses

The mole percentages of each major component of the cyclone exit gas (CO, H_2, CH_4, CO_2, N_2, H_2S, COS, and H_2O) are calculated from the chromatographic analysis results. Permanent gas analyses (expressed as dry, sulfur free mole fractions of CO, CO_2, H_2, N_2, and CH_4) and sulfur gas analyses (expressed as absolute concentrations of sulfur containing species in PPM) are performed in the gas chromatography laboratory. The permanent gas mole fractions are converted to a dry, sulfur gas containing basis by

$$(y_i)_{dry} = y_i'(1 - y_{H2S} - y_{COS}) \tag{20}$$

$$i = CO, CO_2, CH_4, H_2, N_2$$

where y_i' = mole fraction determined in the permanent gas analysis, and y_{H2S} and y_{COS} are the mole fractions of H_2S and COS in the cyclone exit gases. (All other sulfur gases are negligible for char runs). Mole fractions on a wet basis are given by

$$(y_i)_{wet} = (y_i)_{dry} (1 - y_{H2O}) \tag{21}$$

$$i = CO, CO_2, CH_4, H_2, N_2, H_2S, COS$$

where y_{H2O} is the mole fraction of water in the cyclone gas determined from sample train measurements.

The molar flow rate of component i is given by

$$q_i = Q_{cyc} (y_i)_{wet} \qquad i = 1,\ldots,8 \tag{22}$$

where Q_{cyc} is the total molar flow rate determined from Eqs. (B11) - (B14). The values of $(y_i)_{wet}$, $(y_i)_{dry}$, and q_i are printed out for each gas constituent.

The mole fraction of water in the PCS exit gas, y_w, is calculated from Eq. (B12), and the PCS dry gas composition is assumed to be identical to that of the cyclone gas (this is probably a reasonable assumption for the permanent gases, but may not be valid for the sulfur gases). The PCS gas composition on a wet basis is calculated as

$$(y_i)_{wet} = (y_i)_{dry} (1 - y_w) \tag{23}$$

The component molar flow rates are calculated as

$$q_i = Q_{pcs} (y_i)_{wet} \quad i = 1,\ldots,8 \tag{24}$$

As before, $(y_i)_{wet}$, $(y_i)_{dry}$, and q_i are printed out for each species.

Elemental Material Balances

Let w denote mass flow rate (lb/hr).

a. Coal in.
Let x_i denote the mass fraction of element i determined by ultimate analysis.

$$w_{mass} = Q_s \quad \text{(solid feed rate)} \tag{25}$$

$$w_i = x_i Q_i \qquad i = C, H, O, N, S \tag{26}$$

b. Gases in.

$$w_{mass} = (w_i)_{feed} \tag{27}$$

$i = H_2O$, N , O , purge N

$$w_H = (w_{H2O})_{feed} (2/18) \tag{28}$$

$$w_0 = (w_{H2O})_{feed}\,(16/18) + (w_0)_{feed} \qquad (29)$$

$$w_{N2} = w_{N2} + w_{purge\ N2} \qquad (30)$$

c. Total input.

$$w_j = (w_j)_{coal} + (w_j)_{gases} \qquad (31)$$

j = mass, C, H, O, N, S

d. Char out.

Eqs. (B25) and (B26), except that Q_{ch} replaces Q_s.

e. Dust out.

Eqs. (B25) and (B26), except that Q_{dust} [determined from Eq. (B19)] replaces Q_s.

f. Gases out.

Let q_i be the molar flow rate of the i^{th} species in the cyclone exit gas, and M_i the molecular weight of this species.

$$w_{mass} = q_i\,M_i \qquad (32)$$

i = CO, H_2 , CH_4, CO_2, N_2, H_2S, COS, H_2O

$$w_C = 12.01(q_{CO} + q_{CO2} + q_{CH4} + q_{COS}) \qquad (33)$$

$$w_H = 1.008(2q_{H2} + 4q_{CH} + 2q_{H2S} + 2q_{H2O}) \tag{34}$$

$$w_O = 16.00(q_{CO} + 2q_{CO2} + q_{H2O} + q_{COS}) \tag{35}$$

$$w_N = 28.01q_{N2} \tag{36}$$

$$w_S = 32.064(q_{H2S} + q_{COS}) \tag{37}$$

g. Wastewater.

All w_i's are negligible ($w_i = 0$).

h. Total output.

$$w_j = (w_j)_{char} + (w_j)_{dust} + (w_j)_{gases} + (w_j)_{wastewater} \tag{38}$$

j = mass, C, H, O, N, S

i. Percent recovery.

$$PCT_j = [(w_j)_{output}/(w_j)_{input}](100\%) \tag{39}$$

j = mass, C, H, O, N, S

Feed and Effluent Temperatures, and Energy Balance

The temperature of the coal and gas streams entering the gasifier are printed as read in. The char output temperature is assumed equal to the average temperature of the bed. The gas output temperature is taken as equal to the reading of the top thermocouple in the reactor.

The energy input to the reactor is the sum of kinetic energy of the feed gases and the enthalpy of the feed streams. Dulong's formula is used to calculate the heat of formation of the coal and char. The energy output is calculated similarly. The percent heat loss is calculated as

$$HL = [(E_{in} - E_{out})/E_{in}]\ (100\%) \qquad (40)$$

Trap Water Analysis

The trap water pH and the concentration (in mg/liter) of each analyzed species are printed as read in.

The production rate (in lb/hr) of species i is calculated using Eq. (B41).

$$q_i = 1.8016 \times 10^{-7} \quad Q_{cyc}\ y_{H2O} C_i \qquad (41)$$

where Q_{cyc} is the total molar flow rate of the cyclone gas, y_{H2O} is the mole fraction of water in the gas, and c_i is the concentration of the species i (in mg/liter) in the trap water.

The production rate per pound of coal fed is calculated for each species by

$$q_i' = q_i/Q_s \qquad (42)$$

where Q_s is the coal feed rate in lb/hr.

Trace Element Analysis

The concentration of each trace element analyzed in the coal, char, cyclone dust, and cyclone exit gas are printed as read in.

The flow rates of each trace element in each stream analyzed are calculated by multiplying the mass fraction of each element by the flow rate of the appropriate stream. These flow rates are printed along with the total trace element flow out of the reactor (sum of char, cyclone dust, and gas flows) for each trace element.

The percent recovery of trace element i is calculated using the following equation:

$$P_i = [(q_i)_{out}/(q_i)_s] \times 100\% \tag{43}$$

where $(q_i)_{out}$ is the sum of flows of trace element i in the char, cyclone dust, and cyclone gas, and $(q_i)_s$ is the flow rate of trace element i in the feed coal.

In addition, enrichment ratios are calculated and printed. The enrichment ratio expresses the nature of the distribution of each trace element among the effluent streams. The definition of enrichment ratio used in this study is the ratio of the mass flow rate of a trace element in a stream to the mass flow rate of ash in that stream, normalized by the corresponding ratio for the feed coke. The enrichment ratio for each trace element i in each outlet stream j is

$$R_{ij} = [(q_i)_j/A_j]/[(q_i)_s/A_s] \tag{44}$$

where $(q_i)_j$ and $(q_i)_s$ are the mass flow rates of trace element i in stream j and the feed coke, and A_j and A_s are the mass flow rates of ash in stream j and the feed coke. An enrichment ratio greater than one or less than one indicates that the element is enriched or depleted, respectively, in that stream relative to the ash.

```
                              RUN GO-44B  1/22/80  11:15-14:30
DATA ECHO

CARD  1 : ALAB  =                          RUN GO-44B  1/22/80  11:15-14:30

CARD  2 : ALABC = WESTERN KENTUCKY #11 COAL CHAR, 10X80 MESH

CARD  3 : ISIM,PRES,HT,DIAM,RLEAK,PDEN,PBULK = 1   101.6  38.00   6.00   0.53   112.2    46.2

CARD  4 : IHB(1),...,IHB(6) =    5   10   25   35   45   55

CARD  5 : TRP(1),...,TRP(7) =    1722.3    1714.4    1688.4    1678.2    1646.4    1576.7    1076.2

CARD  6 : XMAR,XMOIS,XASH,XVOLA =  0.0109    0.0087  0.1086  0.0087
          XULT(1),...,XULT(4) =  0.8216  0.0043  0.0014  0.0265

CARD  7 : QINC,QINH2O,QINO2,QINN2,TINC,TIN = 34.7  55.85   1.89   1.35    200.0    988.9

CARD  8 : IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP =  1    212.0    143.5  12.0    21.8    9.5
          QPCSV,TPCS,PPCS,QSTV,NWFC =   10.79    68.8    98.8    0.41     0

CARD  9 : QPURN2,TINPN2,PINPN2,TINH2O,PINH2O = 181.6      78.2  101.6     365.3   150.0
          TINO2,PINO2,TINN2,PINN2 =      78.9   129.1      78.2  147.2

CARD 10 : TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2 =      365.3   150.0       78.9   129.1      78.2   147.2
          TCPN2,PCPN2,TCPCS,PCPCS =      70.0   100.0      68.8    98.8

CARD 11 : ACYC(1),...,ACYC(9) =    0.000   15.590   23.880    2.110   20.820   37.560    0.651    0.028
                                  57.380
CARD 12 : APCS(1),...,APCS(8) =    0.000   15.590   23.880    2.110   20.820   37.560    0.651    0.028

CARD 13 : XMARCH,XMCH,XASHCH,XVOLCH =  0.0016    0.0017  0.1196  0.0017
          XUCH(1),...,XUCH(4) =  0.8301  0.0036  0.0036  0.0189

CARD 14 : XMARCY,XMCY,XASHCY,XVOLCY =  0.1198    0.1166  0.1896  0.0506
          XUCY(1),...,XWCY(4) =  0.6604  0.0052  0.0080  0.0158

CARD 15 : QSCRUB,DPT232,TT234,PCSWT,PCSWL =    71.5   23.35   220.0    80.0    28.0

CARD 16 : XDP(1),...,XDP(10) =  0.0270  0.2830  0.1360  0.1410  0.2000  0.0950  0.0400  0.0520  0.0170
                                0.0090(CALCULATED)
CARD 17 : PH,NTW,NT =  0.00     0    2

CARD 18 : TNAM,CMW,CTC,CTCH,CTCYD,CTW,CTG = AS  74.92200   8.40000   9.40000  15.50000   0.05500   0.00000

CARD 19 : TNAM,CMW,CTC,CTCH,CTCYD,CTW,CTG = PB 207.19000   2.50000   2.80000   6.40000   0.14000   0.00000
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                          *                                         *
                          * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                          *                                         *
                          * FLUIDIZED BED COAL GASIFICATION REACTOR *
                          *                                         *
                          *******************************************

                                RUN GO-44B  1/22/80  11:15-14:30

        REACTOR SPECIFICATIONS                              SOLID FEED PROPERTIES

PRESSURE     = 101.6 PSIG ( 801.7 KPA)
TEMPERATURE = 1699.8 DEG.F ( 926.5 DEG.C)    WESTERN KENTUCKY #11 COAL CHAR, 10X80 MESH
BED HEIGHT  = 38.0 IN. (0.97 METERS)         PARTICLE DENSITY          = 112.2 LB/FT**3 (1.797 G/CM**3)
BED DIAMETER=  6.0 IN. (0.152 METERS)        SETTLED BED DENSITY       =  46.2 LB/FT**3 (0.740 G/CM**3)
ESTIMATED BED VOIDAGE = 0.74                 AVERAGE PARTICLE DIAMETER  = 493.85 MICRONS
BED EXPANSION FACTOR  = 1.56                 A-R MOISTURE CONTENT       = 0.0109
ESTIMATED LEAK RATE   = 0.53 SCFM


   PROXIMATE ANALYSIS OF COAL FEED                        ULTIMATE ANALYSES

                                                     COAL FEED   SPENT CHAR   CYCLONE DUST

      FIXED CARBON    = 0.872                CARBON    0.820        0.830         0.658
      VOLATILE MATTER = 0.009                HYDROGEN  0.005        0.004         0.006
      MOISTURE        = 0.011                OXYGEN    0.039        0.024         0.124
      ASH             = 0.108                NITROGEN  0.001        0.004         0.008
                                             SULFUR    0.026        0.019         0.016
                                             ASH       0.108        0.120         0.189


              FEED RATES                             FEED RATIOS AND CONDITIONS


COAL      = 34.69 LB/HR AT  200.0 DEG.F      STEAM/COAL = 1.83 LB STEAM/LB COAL(MAF)
          = 15.74 KG/HR AT   93.3 DEG.C                 = 1.31 MOLES STEAM/MOLE CARBON

STEAM     = 55.85 LB/HR AT  365.3 DEG.F      O2/COAL    = 0.33 LB O2/LB COAL(MAF)
          = 25.33 KG/HR AT  185.2 DEG.C                 = 0.13 MOLES O2/MOLE CARBON

OXYGEN    = 10.10 LB/HR AT   78.9 DEG.F      N2/O2      = 0.71 MOLES N2/MOLE O2
          =  4.58 KG/HR AT   26.1 DEG.C
          =  1.89 SCFM                       COMBINED GAS FEED TEMPERATURE =  988.9 DEG.F
                                                                           =  531.6 DEG.C

NITROGEN =  6.32 LB/HR AT   78.2 DEG.F
         =  2.87 KG/HR AT   25.7 DEG.C       SUPERFICIAL GAS VELOCITY IN REACTOR = 1.03 FT/S
         =  1.35 SCFM                                                            = 0.31  M/S

PURGE N2 = 14.16 LB/HR ( 3.02 SCFM)          V(MIN.FLUID.)    = 0.221 FT/S ( 6.7 CM/S)
         =  6.42 KG/HR                       VS/V(MIN.FLUID.) = 4.7
```

```
                              RUN GO-44B  1/22/80  11:15-14:30


          CONTROL VARIABLES                                      OUTPUT VARIABLES

TEMPERATURE               = 1699.8 DEG.F          PRESSURE DROP OVER 20 IN.  =  9.5 IN.H2O ( 0.345 PSI)
N2/O2 MOLAR FEED RATIO = 0.71                                                =  2.4 KPA
STEAM PARTIAL PRESSURE = 98.98 PSI                PCS GAS FLOW RATE          =  1.96 LB-MOLE/HR (11.73 SCFM)
BED HEIGHT                = 3.17 FT                                          =  1.95 LB-MOLE/HR(DRY BASIS)
SOLID SPACE TIME          = 31.8 MIN              CYCLONE GAS FLOW RATE      =  4.59 LB-MOLE/HR (27.44 SCFM)
GAS SPACE TIME            = 3.07 S                                           =  1.95 LB-MOLE/HR(DRY BASIS)
                                                                             =  2.08 KMOL/HR
                                                  SOLID HOLDUP               =  18.4 LB ( 8.3 KG)



          PRODUCT FUEL PROPERTIES                                CONVERSION VARIABLES

 CO  = 20.9% (MOLAR BASIS)                              CARBON CONVERSION = 31.6%
     = 0.278 LB  CO PRODUCED/LB COAL(MAF)               STEAM CONVERSION  = 15.3%
 H2  = 32.0% (MOLAR BASIS)                              SULFUR CONVERSION = 46.3%
     = 0.031 LB  H2 PRODUCED/LB COAL(MAF)
 CH4 =  2.8% (MOLAR BASIS)                                SOLID MATERIAL BALANCE
     = 0.022 LB CH4 PRODUCED/LB COAL(MAF)

 HEATING VALUE OF MAKE GAS  =  3167.3 BTU/LB          COAL FED               = 212.0 LB
                            =   210.7 BTU/SCF         SPENT CHAR COLLECTED   = 143.5 LB = 67.7% OF FEED
                            =  7361.1 KJ/KG           CYCLONE DUST COLLECTED =  12.0 LB =  5.7% OF FEED
                                                      COAL GASIFIED          =  56.5 LB = 26.7% OF FEED
 HEATING VALUE OF SWEET GAS =  6705.6 BTU/LB
                            =   296.0 BTU/SCF         SPENT CHAR REMOVAL RATE    = 21.8 LB/HR
                            = 15584.2 KJ/KG           CHAR RATE FOR MASS BALANCE = 23.1 LB/HR


               CYCLONE EXIT GAS ANALYSIS          PCS EXIT GAS ANALYSIS

               %WET     %DRY  LBMOL/HR            %WET     %DRY  LBMOL/HR

         CO     6.60   15.49   0.303              15.44   15.49   0.303
         H2    10.11   23.73   0.464              23.65   23.73   0.464
         CH4    0.89    2.10   0.041               2.09    2.10   0.041
         CO2    8.82   20.69   0.404              20.62   20.69   0.404
         N2    15.91   37.32   0.729              37.21   37.32   0.729
         H2S    0.28    0.65   0.013               0.65    0.65   0.013
         COS    0.01    0.03   0.001               0.03    0.03   0.001
         H2O   57.38           2.631               0.31           0.006

         H2S = 6510.0 PPM(DRY)
         COS =  283.0 PPM(DRY)
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                        RUN GO-44B  1/22/80  11:15-14:30

                  ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

                      MASS     C       H       O       N       S

             COAL     34.7   28.44    0.16    1.37    0.05   0.918
            GASES     86.4    0.00    6.25   59.70   20.47   0.000
      TOTAL INPUT    121.1   28.44    6.41   61.06   20.52   0.918

             CHAR     21.8   18.10    0.08    0.53    0.08   0.412
             DUST      1.8    1.20    0.01    0.23    0.01   0.029
            GASES     96.2    8.99    6.43   59.88   20.43   0.426
       WASTEWATER      0.0    0.00    0.00    0.00    0.00   0.000
     TOTAL OUTPUT    119.8   28.29    6.52   60.64   20.52   0.866

     % RECOVERY      98.9%   99.5%  101.8%   99.3%  100.0%   94.3%


FEED AND EFFLUENT TEMPERATURES                         ENERGY BALANCE


  COAL IN   =  200.0 DEG.F                  ENERGY IN   = -2.90E+05 BTU/HR ( -3.05E+05 KJ/HR)
  GASES IN  =  988.9 DEG.F                  ENERGY OUT  = -2.85E+05 BTU/HR ( -3.00E+05 KJ/HR)
                                            HEAT LOSS   = -5.03E+03 BTU/HR ( -5.30E+03 KJ/HR)
  CHAR OUT  = 1699.8 DEG.F
  GASES OUT = 1576.7 DEG.F                  % HEAT LOSS =  -1.7%


                         TRAP WATER ANALYSIS

                            PH =  0.00
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                    RUN GO-44B  1/22/80  11:15-14:30


                         TRACE ELEMENT ANALYSIS: PPM

ELEMENT       IN COAL      IN CHAR      IN DUST      IN WATER      IN GAS

  AS         8.400E+00    9.400E+00    1.550E+01    5.500E-02    0.000E-01
  PB         2.500E+00    2.800E+00    6.400E+00    1.400E-01    0.000E-01



                 TRACE ELEMENT MATERIAL BALANCE: FLOWS IN LB/HR

                  IN                        OUT

ELEMENT          COAL          CHAR       DUST        GAS       TOTAL OUT   % RECOVERY

  AS           2.914E-04    2.049E-04  2.826E-05  5.745E-09   2.332E-04     80.0%
  PB           8.672E-05    6.104E-05  1.167E-05  1.462E-08   7.272E-05     83.9%



              TRACE ELEMENT ENRICHMENT RATIOS;REFERENCE ASH CONTENT
                     ELEMENT       CHAR         DUST
                       AS        1.014E+00    8.851E-02
                       PB        1.015E+00    1.228E-01
                 *******************************************
                 *                                         *
                 * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                 *                                         *
                 * FLUIDIZED BED COAL GASIFICATION REACTOR *
                 *                                         *
                 *******************************************

                       RUN GO-44B  1/22/80  11:15-14:30

 COAL FEED                               *****
 34.7 LB/HR                 GAS OUTPUT   *   *
------------------->    :--------------->*   *-------------------->:
 0.8198 C          :    :   T = 1076 F   *   *                     :
 0.0046 H          :    :   57.4% H2O    *   *                     :
 0.0394 O          :    :                *****              :---->:
 0.0014 N          V    :               CYCLONE             :     :
 0.0265 S     *****************                             :     :
 0.1084 ASH   *               *                             :    ):( VENTURI SCRUBBER
              *   GASIFIER    *                       SCRUB :     :  DP =23.4 IN.H2O
              *     TEMP.     *                       WATER :     :  T(OUT) = 219 F
              *    PROFILE    *                             :     :
              *               *                    28.6 GPH :     :
              *               *                             :     :               SOUR GAS
              *               *                             :     :        :----------------->
              * 55''   1576 F *                             :     :        :      11.7 SCFM
              *               *                             :     :        :      68.8 F
              *               *                             :     V        :      98.8 PSIG
              * 45''   1646 F *      GASIFIER               :   **************
              *               *                             :   *            *    15.4% CO
              *               *  T(AV) =  1699 F            :   *            *    23.7% H2
              * 35''   1678 F *  P(AV) = 101.6 PSIG         :   *            *     2.1% CH4
              *               *  BED LEVEL    = 38.0 IN     :   *            *    20.6% CO2
              *               *  SOLID HOLDUP = 18.4 LB     :   *            *    37.2% N2
              * 25''   1688 F *                             :   * T =  80 F  *     0.3% H2O
              *               *  C CONVERSION = 31.6%       :   *            *
              *               *                             :   * V = 193 GAL*     6510 PPM H2S
              * 10''   1714 F *                             :   *            *      283 PPM COS
              *               *                             :   *            *
              *               *                             :   *            *
              *  5''   1722 F *                             <---*            *
              *               *                                 *            *
              *****************                                 **************
                   :    :                                         PCS TANK
                   :    :
 CHAR REMOVAL      :    :
 21.8 LB/HR        :    :   GAS FEED
<------------------:    <------------------------
 0.8301 C                   55.9 LB/HR H2O
 0.0036 H                   1.89 SCFM O2
 0.0242 O                   1.35 SCFM N2
 0.0036 N
 0.0189 S                   1.31 MOLES H2O/MOLE C
 0.1196 ASH                 0.71 MOLES N2/MOLE O2
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APPENDIX C

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C *** PROGRAM GMOD -- DATA ANALYSIS AND MODELING FOR NCSU COAL GASIFICATION
C ***    REACTOR. PROGRAM WRITTEN BY R.M.FELDER
      COMMON/BLK1/ALAB(20),ALABC(15),ISIM,PRES,TR,HT,DIAM,RLEAK,PDEN,
     1 PBULK
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK4/IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS,QPURN2
     1,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,PINN2
      COMMON/BLK5/TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2,TCPN2,PCPN2,TCPCS,
     1 PCPCS,QSTV,MWFC
      COMMON/BLK6/ACYC(9),APCS(9),YCYC(9),YCYCD(8),YPCS(9),YPCSD(8)
      COMMON/BLK7/XMARCH,XMCH,XASHCH,XVOLCH,XUCH(5),XMARCY,XMCY,XASHCY,
     1 XVOLCY,XUCY(5)
      COMMON/BLK8/XMW(9),TC(9),PC(9),ZC(9),VC(9)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1  WINO2,WINN2,TGOUT
      COMMON/BLK10/ NT,TNAM(20),CTC(20),CTCH(20),CTCYD(20),CTW(20),
     1 CMW(20),CTG(20),QEL(7,6)
      COMMON/BLK11/PH,NTW,SPW(25),CWATR(25)
      COMMON/BLK12/TRP(7),IHB(7),QSCRUB,DPT232,TT234,PCSWT,PCSWL,PCSWV,
     1  QS,QT,H2SP,COSP,CCONV,XMASS,TCE,TVI
C...
C...    SET UP OUTPUT FILE
C...
        OPEN (UNIT=3,TYPE='NEW',FORM='FORMATTED',NAME='DL1:LP.LST')
  100 CALL INPUT
      CALL LOG
      CALL ENERGY
      CALL WATER
      IF(NT.GT.0) CALL TRACE
      CALL GPLOT
      GO TO 100
      END
      BLOCK DATA
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK8/XMW(9),TC(9),PC(9),ZC(9),VC(9)
      COMMON/BLK12/TRP(7),IHB(7),QSCRUB,DPT232,TT234,PCSWT,PCSWL,PCSWV,
     1  QS,QT,H2SP,COSP,CCONV,XMASS,TCE,TVI
C *** SUBSCRIPT KEY : 1=O2,2=CO,3=H2,4=CH4,5=CO2,6=N2,7=H2S,8=COS,9=H2O
      DATA XMW/31.99,28.01,2.02,16.04,44.01,28.01,34.08,60.07,18.02/
      DATA  TC/154.4,133.0,33.3,190.7,304.2,126.2,373.2,375.0,647.4/
      DATA  PC/49.7,  4.5, 12.8, 45.8, 72.9, 33.5,88.2,58.0,218.3/
      DATA  ZC/0.29,0.29,0.30,0.29,0.28,0.29,0.28, 0.26, 0.23/
      DATA  VC/74.0, 93.0, 65.0, 99.0, 94.0, 90.0, 98.5,140.0,56.0/
      DATA  DP/1410.0,841.0,595.0,420.0,250.0,177.0,149.0,74.0,44.0,30./
      END
      SUBROUTINE INPUT
      COMMON/BLK1/ALAB(20),ALABC(15),ISIM,PRES,TR,HT,DIAM,RLEAK,PDEN,
     1 PBULK
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK4/IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS,QPURN2
     1,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,PINN2
      COMMON/BLK5/TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2,TCPN2,PCPN2,TCPCS,
     1 PCPCS,QSTV,MWFC
      COMMON/BLK6/ACYC(9),APCS(9),YCYC(9),YCYCD(8),YPCS(9),YPCSD(8)
      COMMON/BLK7/XMARCH,XMCH,XASHCH,XVOLCH,XUCH(5),XMARCY,XMCY,XASHCY,
     1 XVOLCY,XUCY(5)
      COMMON/BLK8/XMW(9),TC(9),PC(9),ZC(9),VC(9)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1 WINO2,WINN2,TGOUT
      COMMON/BLK10/NT,TNAM(20),CTC(20),CTCH(20),CTCYD(20),CTW(20),
     1 CMW(20),CTG(20),QEL(7,6)
      COMMON/BLK11/PH,NTW,SPW(25),CWATR(25)
      COMMON/BLK12/TRP(7),IHB(7),QSCRUB,DPT232,TT234,PCSWT,PCSWL,PCSWV,
     1  QS,QT,H2SP,COSP,CCONV,XMASS,TCE,TVI
    1 FORMAT(1X,19A4,A3)
    2 FORMAT(I1,7X,9F8.2)
    3 FORMAT(10F8.2)
    4 FORMAT('0','DATA ECHO'///' CARD  1 : ALAB  = ',20A4/'0CARD  2 : ALA
     1BC = ',20A4/)
    5 FORMAT('0CARD ',I2,' : ISIM,PRES,HT,DIAM,RLEAK,PDEN,PBULK =',I2,
     1 F8.1,3F7.2,2F8.1)
    6 FORMAT('0CARD ',I2,' : XMAR,XMOIS,XASH,XVOLA =',F8.4,2X,3F8.4/11X,
     1'XULT(1),...,XULT(4) =',4F8.4)
    8 FORMAT('0CARD ',I2,' : XDP(1),...,XDP(10) =',10F8.4,'(CALCULATED)'
     1)
    9 FORMAT('0CARD ',I2,' : QINC,QINH2O,QINO2,QINN2,TINC,TIN =',F5.1,
     1 3F7.2,2F9.1)
   10 FORMAT('0CARD ',I2,' : IPR,FO,TRANS,ADJ(1),...,ADJ(6) =',I3,F6.2,
     1 8F8.2)
   11 FORMAT('0CARD ',I2,' : IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP =',I3,2F9.1
     1,F7.1,F8.1,F7.1/11X,'QPCSV,TPCS,PPCS,QSTV,MWFC =',F8.2,2F8.1,F8.2,
     25X,I1)
   12 FORMAT('0',40X,43('*')/41X,'*',41X,'*'/41X,'* NCSU DEPARTMENT OF C
     1HEMICAL ENGINEERING *'/41X,'*',41X,'*'/41X,'* FLUIDIZED BED COAL G
     2ASIFICATION REACTOR *'/41X,'*',41X,'*'/41X,43('*')///2X,20A4)
   13 FORMAT('0CARD ',I2,' : ACYC(1),...,ACYC(9) =',8F9.3,2X,F9.3)
   14 FORMAT('0CARD ',I2,' : APCS(1),...,APCS(8) =',8F9.3)
   15 FORMAT('0CARD ',I2,' : XMARCH,XMCH,XASHCH,XVOLCH =',F8.4,2X,3F8.4/
     111X,'XUCH(1),...,XUCH(4) =',4F8.4)
   16 FORMAT('1')
   17 FORMAT('0CARD ',I2,' : XMARCY,XMCY,XASHCY,XVOLCY =',F8.4,2X,3F8.4/
     111X,'XUCY(1),...,XUCY(4) =',4F8.4)
   18 FORMAT('0',20A4)
   19 FORMAT('0CARD ',I2,' : QPURN2,TINPN2,PINPN2,TINH2O,PINH2O =',F6.1,
     12(F10.1,F8.1)/11X,'TINO2,PINO2,TINN2,PINN2 =',2(F10.1,F8.1))
   20 FORMAT('0CARD ',I2,' : TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2 =',3(F10.1,
     1F8.1)/11X,'TCPN2,PCPN2,TCPCS,PCPCS =',2(F10.1,F8.1))
   21 FORMAT(F10.0,2I10)
   22 FORMAT('0CARD ',I2,' : PH,NTW,NT =',F6.2,2I6)
   23 FORMAT(A2,8X,6F10.2)
   24 FORMAT('0CARD ',I2,' : TNAM,CMW,CTC,CTCH,CTCYD,CTW,CTG = ',A2,
     16F10.5)
   25 FORMAT('0CARD ',I2,' : TRP(1),...,TRP(7) =',7F10.1)
   26 FORMAT('0CARD ',I2,' : QSCRUB,DPT232,TT234,PCSWT,PCSWL =',F8.1,
     1 F8.2,3F8.1)
   27 FORMAT(4(A4,F16.1))
   28 FORMAT('0CARD ',I2,' : SPW(',I2,'),CWATR(',I2,')...SPW(',I2,'),CWA
     1TR(',I2,') = ',4(A4,F8.2,3X))
   29 FORMAT(8I5)
   30 FORMAT('0CARD ',I2,' : IHB(1),...,IHB(6) =',6I5)
   31 FORMAT(I1,7X,8F8.2,F6.2,I1)
   32 FORMAT(I1,7X,6F8.2,I1)
   80 READ(1,1,END=600)ALAB
C **  RUN NUMBER,DATE,KEY CONDITIONS AND COMMENTS(PUNCH IN COLUMNS 2-80)
      WRITE(3,16)
   90 READ(1,1) ALABC
C **  SOURCE AND SCREEN SIZE OF COAL FEED  (PUNCH IN COLUMNS 2-40 ONLY)
      WRITE(3,16)
      WRITE(3,18) ALAB
      WRITE(3,4) ALAB,ALABC
      READ(1,32) ISIM,PRES,HT,DIAM,RLEAK,PDEN,PBULK
C *** ISIM=1 TO LOG, =2 TO SIMULATE, =3 TO LOG AND SIMULATE, =4 TO ESTIMATE
C ***   FEED FOR DESIRED OUTPUT
C *** PRESSURE(PSIG),BED HEIGHT(IN.),BED DIAMETER(IN.)
C *** ESTIMATED LEAK RATE FROM REACTOR,SCFM, COAL DENSITY(LB/FT**3),SETTLED
C ***     BED DENSITY(LB/FT**3)
      NCARD=3
      WRITE(3,5) NCARD,ISIM,PRES,HT,DIAM,RLEAK,PDEN,PBULK
      READ(1,29)(IHB(J),J=1,6)
      IHB(7)=70
      NCARD=NCARD+1
      WRITE(3,30) NCARD,(IHB(J),J=1,6)
      READ(1,3) TRP
C *** T(DEG.F) AT 6 POSITIONS IN GASIFIER(LOWEST FIRST) AND AT CYCLONE
      TGOUT=TRP(6)
      NCARD=NCARD+1
      WRITE(3,25) NCARD,TRP
      READ(1,3) XMAR,XMOIS,XASH,XVOLA,(XULT(J),J=1,4)
C *** COAL FEED ANALYSIS : MASS FRACTIONS OF AS-RECEIVED MOISTURE,PROXIMATE
C ***   MOISTURE,ASH,AND VOLATILE MATTER, ULTIMATE C,H,N,S
      NCARD=NCARD+1
      WRITE(3,6) NCARD,XMAR,XMOIS,XASH,XVOLA,(XULT(J),J=1,4)
      READ(1,3) QINC,QINH2O,QINO2,QINN2,TINC,TIN
C *** FEED RATES OF COAL(LB/HR),STEAM(LB/HR),O2(SCFM),N2(SCFM); FEED
C ***   TEMPERATURES(DEG.F) OF COAL AND COMBINED FEED GAS
C *** GAS FLOW RATES SHOULD COME DIRECTLY FROM CALIBRATION CHART
      NCARD=NCARD+1
      WRITE(3,9) NCARD,QINC,QINH2O,QINO2,QINN2,TINC,TIN
  100 READ(1,31) IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS
     1,QSTV,MWFC
C *** IEXH=1 FOR ROUTINE ANALYSIS, =2 FOR EXHAUSTIVE ANALYSIS
C *** MASS(LB) OF COAL FED,CHAR COLLECTED,DUST COLLECTED,SPENT CHAR REMOVAL
C ***   RATE(LB/HR),PRESSURE DROP(IN.H2O),PCS GAS FLOW RATE(SCFM),PCS GAS T(DEG.
C ***   F) AND P(PSIG), AND SAMPLE TRAIN FLOW RATE(SCFM)
      NCARD=NCARD+1
      WRITE(3,11) NCARD,IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS
     1,QSTV,MWFC
      READ(1,3) QPURN2,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,
     1 PINN2
C *** PURGE N2 FLOW RATE(SCFH), T(DEG.F) AND P(PSIG) OF PURGE N2,STEAM,O2,AND N2
      NCARD=NCARD+1
      WRITE(3,19) NCARD,QPURN2,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,
     1 TINN2,PINN2
      READ(1,3) TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2,TCPN2,PCPN2,TCPCS,PCPCS
C *** CALIBRATION TEMPERATURES(DEG.F) AND PRESSURES(PSIG) OF STEAM,O2,N2,PURGE
C ***   N2, AND PCS EXIT GAS FLOWMETERS
      NCARD=NCARD+1
      WRITE(3,20) NCARD,TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2,TCPN2,PCPN2,
     1 TCPCS,PCPCS
      QINH2O=QINH2O*(TCH2O+459.69)*(PINH2O+14.7)/((TINH2O+459.69)*(PCH2O
     1 + 14.7))
      QINO2=QINO2*(TCO2+459.69)*(PINO2+14.7)/((TINO2+459.69)*(PCO2+14.7
     1 ))
      QINN2=QINN2*(TCN2+459.69)*(PINN2+14.7)/((TINN2+459.69)*(PCN2+14.7
     1 ))
      QPCSV=QPCSV*(TCPCS+459.69)*(PPCS+14.7)/((TPCS+459.69)*(PCPCS+14.7)
     1)
      QPURN2=QPURN2*SQRT((TCPN2+459.69)*(PINPN2+14.7)/((TINPN2+459.69)*
     1 (PCPN2+14.7)))/60.0
```

```
      READ(1,3) ACYC
C *** CYCLONE GAS ANALYSIS : %(DRY,S-FREE) OF O2,CO,H2,CH4,CO2,N2, %(DRY) OF
C ***   H2S,COS , %(WET) OF H2O
      NCARD=NCARD+1
      WRITE(3,13) NCARD,ACYC
      READ(1,3) (APCS(J),J=1,8)
C *** PCS GAS ANALYSIS : %(DRY,S-FREE) OF O2,CO,H2,CH4,CO2,N2, %(DRY) OF H2S,COS
      NCARD=NCARD+1
      WRITE(3,14) NCARD,(APCS(J),J=1,8)
      READ(1,3) XMARCH,XMCH,XASHCH,XVOLCH,(XUCH(J),J=1,4)
C *** SPENT CHAR ANALYSIS : MASS FRACTIONS OF AS-RECEIVED MOISTURE, PROXIMATE
C ***   MOISTURE,ASH,AND VOLATILE MATTER, ULTIMATE C,H,N,S
      NCARD=NCARD+1
      WRITE(3,15) NCARD,XMARCH,XMCH,XASHCH,XVOLCH,(XUCH(J),J=1,4)
      READ(1,3) XMARCY,XMCY,XASHCY,XVOLCY,(XUCY(J),J=1,4)
C *** CYCLONE DUST ANALYSIS : MASS FRACTIONS OF AS-RECEIVED MOISTURE, PROXIMATE
C ***   MOISTURE,ASH,AND VOLATILE MATTER, ULTIMATE C,H,N,S
      NCARD=NCARD+1
      WRITE(3,17) NCARD,XMARCY,XMCY,XASHCY,XVOLCY,(XUCY(J),J=1,4)
      READ(1,3) QSCRUB,DPT232,TT234,PCSWT,PCSWL,TCE,TVI
C *** % SCRUBBER PUMP CAPACITY, VENTURI DP(IN.H2O), VENTURI EXIT TEMP.(DEG.F),
C ***   PCS WATER TEMP(DEG.F),LEVEL(IN.H2O)
      NCARD=NCARD+1
      WRITE(3,26) NCARD,QSCRUB,DPT232,TT234,PCSWT,PCSWL
      READ(1,3) (XDP(J),J=1,9)
C *** MASS FRACTIONS ON ALL BUT LAST SCREEN
      NCARD=NCARD+1
      XDP(10)=1.0
      DO 105J=1,9
  105 XDP(10)=XDP(10)-XDP(J)
      WRITE(3,8) NCARD,XDP
      READ(1,21) PH,NTW,NT
C *** PH OF SAMPLE TRAP WATER, # SPECIES ANALYZED IN WATER, # TRACE ELEMENTS
C ***   ANALYZED
      NCARD= NCARD+1
      WRITE(3,22) NCARD,PH,NTW,NT
      IF(NTW.EQ.0) GO TO 250
      READ(1,27) (SPW(J),CWATR(J),J=1,NTW)
C *** SPECIES NAME,CONCENTRATION(MG/L)
      KKI=1
      KKF=4
      DO 200I=1,10
      NCARD=NCARD+1
      IF(NTW.LE.KKF) GO TO 210
      WRITE(3,28) NCARD,KKI,KKI,KKF,KKF,(SPW(J),CWATR(J),J=KKI,KKF)
      KKI=KKI+4
      KKF=KKF+4
  200 CONTINUE
  210 WRITE(3,28) NCARD,KKI,KKI,NTW,NTW,(SPW(J),CWATR(J),J=KKI,NTW)
  250 IF(NT.EQ.0) GO TO 500
      DO 300J=1,NT
      READ(1,23) TNAM(J),CMW(J),CTC(J),CTCH(J),CTCYD(J),CTW(J),CTG(J)
C *** TRACE ELEMENT ANALYSIS: NAME,MOLECULAR WT.,CONCENTRATION (UG/G) IN;
C ***  COAL,SPENT CHAR, CYCLONE DUST,TRAP WATER (UG/ML),SAMPLE TRAIN
C ***  GAS (uG/CF)
      NCARD= NCARD+1
      WRITE(3,24) NCARD,TNAM(J),CMW(J),CTC(J),CTCH(J),CTCYD(J),CTW(J)
     1,CTG(J)
  300 CONTINUE
  500 RETURN
  600 STOP
      END
      SUBROUTINE LOG
      DIMENSION HEATV(3),QPP(9),QPM(9),SPEC(9),YT(9),H(6),YM(9),
     1 QMV(9),QMM(9)
      COMMON/BLK1/ALAB(20),ALABC(15),ISIM,PRES,TR,HT,DIAM,RLEAK,PDEN,
     1 PBULK
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK4/IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS,QPURN2
     1,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,PINN2
      COMMON/BLK5/TCH2O,PCH2O,TCO2,PCO2,TCN2,PCN2,TCPN2,PCPN2,TCPCS,
     1 PCPCS,QSTV,MWFC
      COMMON/BLK6/ACYC(9),APCS(9),YCYC(9),YCYCD(8),YPCS(9),YPCSD(8)
      COMMON/BLK7/XMARCH,XMCH,XASHCH,XVOLCH,XUCH(5),XMARCY,XMCY,XASHCY,
     1 XVOLCY,XUCY(5)
      COMMON/BLK8/XMW(9),TC(9),PC(9),ZC(9),VC(9)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1 WINO2,WINN2,TGOUT
      COMMON/BLK10/NT,TNAM(20),CTC(20),CTCH(20),CTCYD(20),CTW(20),
     1 CMW(20),CTG(20),QEL(7,6)
      COMMON/BLK12/TRP(7),IHB(7),QSCRUB,DPT232,TT234,PCSWT,PCSWL,PCSWV,
     1  QS,QT,H2SP,COSP,CCONV,XMASS,TCE,TVI
      DATA HEATV/1.218E5,1.230E5,3.831E5/
      DATA SPEC/'O2 ','CO ','H2 ','CH4','CO2','N2 ','H2S','COS','H2O'/
   11 FORMAT(16X,'BED EXPANSION FACTOR  =',F5.2,T67,'A-R MOISTURE CONTEN
     1T',T94,'=',F7.4)
   12 FORMAT('0',40X,43('*')/41X,'*',41X,'*'/41X,'* NCSU DEPARTMENT OF C
     1HEMICAL ENGINEERING *'/41X,'*',41X,'*'/41X,'* FLUIDIZED BED COAL G
     2ASIFICATION REACTOR *'/41X,'*',41X,'*'/41X,43('*')///16X,20A4)
   13 FORMAT(///24X,'REACTOR SPECIFICATIONS',T80,'SOLID FEED PROPERTIES'
     1 /)
   14 FORMAT(16X,'PRESSURE',T29,'=',F6.1,' PSIG (',F6.1,' KPA)')
   15 FORMAT(16X,'TEMPERATURE',T29,'=',F7.1,' DEG.F (',F6.1,' DEG.C)',
     1 T67,15A4)
   16 FORMAT(16X,'BED HEIGHT',T29,'=',F5.1,' IN. (',F4.2,' METERS)',T67,
     1 'PARTICLE DENSITY',T94,'=',F6.1,' LB/FT**3 (',F5.3,' G/CM**3)')
   17 FORMAT(16X,'BED DIAMETER',T29,'=',F5.1,' IN. (',F5.3,' METERS)',
     1 T67,'SETTLED BED DENSITY',T94,'=',F6.1,' LB/FT**3 (',F5.3,' G/CM*
     2*3)')
   18 FORMAT(16X,'ESTIMATED BED VOIDAGE =',F5.2,T67,'AVERAGE PARTICLE DI
     1AMETER',T94,'=',F7.2,' MICRONS')
   20 FORMAT(22X,'FIXED CARBON',T39,'=',F6.3,T67,'CARBON')
   22 FORMAT(22X,'MOISTURE',T39,'=',F6.3,T67,'OXYGEN')
   23 FORMAT(22X,'ASH',T39,'=',F6.3,T67,'NITROGEN')
   24 FORMAT(T67,'SULFUR')
   25 FORMAT(///30X,'FEED RATES',T75,'FEED RATIOS AND CONDITIONS'//)
   26 FORMAT(16X,'COAL',T26,'=',F6.2,' LB/HR AT ',F6.1,' DEG.F',T67,
     1 'STEAM/COAL',T78,'=',F5.2,' LB STEAM/LB COAL(MAF)'/T26,'=',F6.2,
     2 ' KG/HR AT ',F6.1,' DEG.C',T78,'=',F5.2,' MOLES STEAM/MOLE CARBON
     3')
   27 FORMAT('0',15X,'STEAM',T26,'=',F6.2,' LB/HR AT ',F6.1,' DEG.F',
     1 T67,'O2/COAL',T78,'=',F5.2,' LB O2/LB COAL(MAF)'/T26,'=',F6.2,
     2 ' KG/HR AT ',F6.1,' DEG.C',T78,'=',F5.2,' MOLES O2/MOLE CARBON')
   28 FORMAT('0',15X,'OXYGEN',T26,'=',F6.2,' LB/HR AT ',F6.1,' DEG.F',
     1T67,'N2/O2',T78,'=',F5.2,' MOLES N2/MOLE O2'/T26,'=',F6.2,' KG/HR
     2AT ',F6.1,' DEG.C')
   29 FORMAT(T26,'=',F6.2,' SCFM',T67,'COMBINED GAS FEED TEMPERATURE = '
     1,F6.1,' DEG.F'/T97,'= ',F6.1,' DEG.C')
   30 FORMAT('0',15X,'NITROGEN',T26,'=',F6.2,' LB/HR AT ',F6.1,' DEG.F'/
     1 T26,'=',F6.2,' KG/HR AT ',F6.1,' DEG.C',T67,'SUPERFICIAL GAS VELO
     2CITY IN REACTOR =',F5.2,' FT/S'/T26,'=',F6.2,' SCFM',T103,'=',F5.2
     3,'  M/S')
   31 FORMAT('0',15X,'PURGE N2',T26,'=',F6.2,' LB/HR (',F5.2,' SCFM)',
     1 T67,'V(MIN.FLUID.)    =',F6.3,' FT/S (',F4.1,' CM/S)'/ T26,'=',
     2 F6.2,' KG/HR',T67,'VS/V(MIN.FLUID.) =',F4.1)
   32 FORMAT('0',15X,20A4/)
   33 FORMAT(//  26X,'CONTROL VARIABLES',T81,'OUTPUT VARIABLES'//)
   34 FORMAT(17X,'TEMPERATURE',T41,'=',F7.1,' DEG.F',T67,'PRESSURE DROP
     1OVER 20 IN.'    ,T94,'=',F5.1,' IN.H2O (',F6.3,' PSI)'/17X,'N2/O2 M
     2OLAR FEED RATIO',T41,'=',F5.2,T94,'=',F5.1,' KPA')
   35 FORMAT(17X,'STEAM PARTIAL PRESSURE',T41,'=',F6.2,' PSI',T67,'PCS G
     1AS FLOW RATE',T94,'=',F6.2,' LB-MOLE/HR (',F5.2,' SCFM)'/17X,'BED
     2HEIGHT',T41,'=',F5.2,' FT',T94,'=',F6.2,' LB-MOLE/HR(DRY BASIS)')
   36 FORMAT(17X,'SOLID SPACE TIME',T41,'=',F5.1,' MIN',T67,'CYCLONE GAS
     1 FLOW RATE',T94,'=',F6.2,' LB-MOLE/HR (',F5.2,' SCFM)'/17X,'GAS SP
     2ACE TIME',T41,'=',F5.2,' S',T94,'=',F6.2,' LB-MOLE/HR(DRY BASIS)'/
     3 T94,'=',F6.2,' KMOL/HR')
   37 FORMAT(T67,'SOLID HOLDUP',T94,'=',F6.1,' LB (',F4.1,' KG)')
   39 FORMAT(16X,'CH4 =',F5.1,'% (MOLAR BASIS)'/20X,'=',F6.3,' LB CH4 PR
     1ODUCED/LB COAL(MAF)',T78,'SOLID MATERIAL BALANCE'/)
   43 FORMAT(//19X,'PROXIMATE ANALYSIS OF COAL FEED',T82,'ULTIMATE ANALY
     1SES'//T75,'COAL FEED   SPENT CHAR   CYCLONE DUST'/)
   44 FORMAT(///26X,'PRODUCT FUEL PROPERTIES',T79,'CONVERSION VARIABLES'
     1//)
   45 FORMAT('1')
   46 FORMAT(16X,'CO  =',F5.1,'% (MOLAR BASIS)',T76,'CARBON CONVERSION =
     1',F5.1,'%')
   47 FORMAT(20X,'=',F6.3,' LB  CO PRODUCED/LB COAL(MAF)',T76,'STEAM CON
     1VERSION  =',F5.1,'%')
   48 FORMAT(16X,'H2  =',F5.1,'% (MOLAR BASIS)',T76,'SULFUR CONVERSION =
     1',F5.1,'%'/20X,'=',F6.3,' LB  H2 PRODUCED/LB COAL(MAF)')
   50 FORMAT('0',15X,'HEATING VALUE OF MAKE GAS  =',F8.1,' BTU/LB',T70,
     1 'COAL FED',T94,'=',F6.1,' LB'/43X,'=',F8.1,' BTU/SCF',T70,'SPENT
     2CHAR COLLECTED',T94,'=',F6.1,' LB =',F5.1,'% OF FEED')
   51 FORMAT(43X,'=',F8.1,' KJ/KG',T70,'CYCLONE DUST COLLECTED',T94,'=',
     1 F6.1,' LB =',F5.1,'% OF FEED'/T70,'COAL GASIFIED',T94,'=',F6.1,
     2 ' LB =',F5.1,'% OF FEED')
   52 FORMAT(16X,'HEATING VALUE OF SWEET GAS =',F8.1,' BTU/LB'/43X,'=',
     1 F8.1,' BTU/SCF',T70,'SPENT CHAR REMOVAL RATE',T97,'=',F5.1,' LB/H
     2R'/43X,'=',F8.1,' KJ/KG',T70,'CHAR RATE FOR MASS BALANCE',T97,'=',
     3F5.1,' LB/HR'//)
   53 FORMAT(///35X,'CYCLONE EXIT GAS ANALYSIS',T67,'PCS EXIT GAS ANALYS
     1IS')
   54 FORMAT('0',36X,'%WET',4X,'%DRY',2X,'LBMOL/HR',7X,'%WET',4X,'%DRY'
     1 ,2X,'LBMOL/HR'/)
   55 FORMAT(29X,A3,3X,F6.2,2X,F6.2,2X,F6.3,7X,F6.2,2X,F6.2,2X,F6.3)
   56 FORMAT(' ',T38,'COAL ',T43,F8.1,4F8.2,F8.3)
   57 FORMAT(' ',T38,'GASES',T43,F8.1,4F8.2,F8.3)
   58 FORMAT(' ',T32,'TOTAL INPUT',T43,F8.1,4F8.2,F8.3/)
   59 FORMAT(' ',T38,'CHAR ',T43,F8.1,4F8.2,F8.3)
   60 FORMAT(' ',T38,'DUST ',T43,F8.1,4F8.2,F8.3)
   61 FORMAT(' ',T38,'GASES',T43,F8.1,4F8.2,F8.3)
   62 FORMAT(29X,A3,3X,F6.2,10X,F6.3,7X,F6.2,10X,F6.3/)
   63 FORMAT(' ',T33,'WASTEWATER',T43,F8.1,4F8.2,F8.3)
   64 FORMAT(T31,'TOTAL OUTPUT',T43,F8.1,4F8.2,F8.3/)
   65 FORMAT(' ',T31,'% RECOVERY',T43,6(F7.1,'%')//)
   68 FORMAT('0',44X,'ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR'/)
   69 FORMAT(16X,'ESTIMATED LEAK RATE   =',F5.2,' SCFM'/)
   70 FORMAT(T67,'ASH')
   71 FORMAT('+',T75,F7.3,3X,F10.3,3X,F10.3)
   72 FORMAT(29X,'H2S =',F7.1,' PPM(DRY)'/29X,'COS =',F7.1,' PPM(DRY)')
   73 FORMAT(46X,'MASS',5X,'C',7X,'H',7X,'O',7X,'N',7X,'S'/)
      WRITE(3,45)
      WRITE(3,12) ALAB
      WRITE(3,13)
C     CALCULATE THE AVG BED TEMP (VOLUME-WEIGHTED BASIS)
      SUMT=0.0
      HB=0.0
      DO 100J=1,6
      H(J)=0.5*(IHB(J+1)+IHB(J))
      IF(H(J).GE.HT) GO TO 99
      SUMT=SUMT+(H(J)-HB)*TRP(J)
      GO TO 100
   99 IF(IHB(J).GT.HT) GO TO 98
      SUMT=SUMT+(HT-HB)*TRP(J)
      GO TO 110
   98 SUMT=SUMT+(HT-HB)*TRP(J-1)
      GO TO 110
  100 HB=H(J)
  110 TR=SUMT/HT
C     UNITS CONVERSIONS
      PRESA=PRES+14.696
      PATM=PRESA/14.696
      PKP=PATM*101.325
      WRITE(3,14) PRES,PKP
      TRA=TR+459.69
      TK=TRA/1.8
      TY=TK-273.16
      WRITE(3,15) TR,TY,ALABC
      HTM=HT/39.37
      PDENC=PDEN/62.43
      WRITE(3,16) HT,HTM,PDEN,PDENC
      HT=HT/12.0
      DM=DIAM/39.37
      PBULKC=PBULK/62.43
      WRITE(3,17) DIAM,DM,PBULK,PBULKC
      AREA=0.785398*(DIAM**2-0.3875**2)/144.0
      DIAM=DIAM/12.0
      DPX=DELTAP*14.696/406.8
      DPXA=DPX*101.325/14.696
C
      ASFREE=0.0
      DO 133J=1,6
  133 ASFREE=ASFREE+ACYC(J)
      PFIX=100.0-ACYC(7)-ACYC(8)
      DO 134J=1,6
  134 ACYC(J)=ACYC(J)*PFIX/ASFREE
      YV=ACYC(9)/100.0
      ADRY=0.0
      DO 135J=1,8
  135 ADRY=ADRY+ACYC(J)
      ACYC(9)=ADRY*YV/(1.0-YV)
      CALL YCALC(ACYC,YCYC,YCYCD)
      AMMW=0.0
      DO 140J=1,9
  140 AMMW=AMMW+YCYC(J)*XMW(J)
      RHOG=(PATM/(0.7302*TRA))*(AMMW/100.0)
      RHOA=DPX*144.0/(20.0/12.0)
      VOID=(PDEN-RHOA)/(PDEN-RHOG)
      PDA=0.0
      DO 145J=1,10
  145 PDA=PDA+XDP(J)*DP(J)
      WRITE(3,18) VOID,PDA
      PBULKA=PDEN*(1.0-VOID)
      EXPF=PBULK/PBULKA
      WRITE(3,11) EXPF,XMAR
      WRITE(3,69) RLEAK
      WRITE(3,43)
      CALL XCORR(XMAR,XMOIS,XASH,XULT,QAR,1)
      XVOLA=XVOLA/QAR
      XFIXA=1.0-XVOLA-XMOIS-XASH
   21 FORMAT(22X,’VOLATILE MATTER’,T39,’=’,F6.3,T67,’HYDROGEN’)
      CALL XCORR(XMARCH,XMCH,XASHCH,XUCH,QARCH,2)
      CALL XCORR(XMARCY,XMCY,XASHCY,XUCY,QARCY,3)
      WRITE(3,20) XFIXA
      WRITE(3,71) XULT(1),XUCH(1),XUCY(1)
      WRITE(3,21) XVOLA
      WRITE(3,71) XULT(2),XUCH(2),XUCY(2)
      WRITE(3,22) XMOIS
      WRITE(3,71) XULT(5),XUCH(5),XUCY(5)
      WRITE(3,23) XASH
      WRITE(3,71) XULT(3),XUCH(3),XUCY(3)
      WRITE(3,24)
      WRITE(3,71) XULT(4),XUCH(4),XUCY(4)
      WRITE(3,70)
      WRITE(3,71) XASH,XASHCH,XASHCY
      WINH2O=QINH2O/XMW(9)
      WINO2=QINO2*60.0/359.05
      WINN2=QINN2*60.0/359.05
      WTOT=WINH2O+WINO2+WINN2
      IF(ISIM.EQ.4) GO TO 300
      WRITE(3,25)
      QX=QINC*0.453593
      QIDC=QINC*(1.0-XMOIS)
      WIMC=(QINC-QIDC)/XMW(9)
      QMAF=QINC*(1.0-XMOIS-XASH)
      QCAR=QINC*XULT(1)/12.01
      QR=QINH2O/QMAF
      QS=WINH2O/QCAR
      TX=(TINC-32.0)/1.8
      WRITE(3,26) QINC,TINC,QR,QX,TX,QS
      QY=QINH2O*0.453593
      QX=WINO2*XMW(1)
      QR=QX/QMAF
      QSO=WINO2/QCAR
      TX=(TINH2O-32.0)/1.8
      WRITE(3,27) QINH2O,TINH2O,QR,QY,TX,QSO
      QY=QX*0.453593
      QT=WINN2/WINO2
      TX=(TINO2-32.0)/1.8
      WRITE(3,28) QX,TINO2,QT,QY,TX
      TX=(TIN-32.0)/1.8
      WRITE(3,29) QINO2,TIN,TX
      QZ=WINN2*XMW(6)
      QY=QZ*0.453593
      TX=(TINN2-32.0)/1.8
      VS=WTOT*359.05*(TRA/491.69)*(1.0/PATM)/(3600.0*AREA)
      VSC=VS*0.3048
      WRITE(3,30) QZ,TINN2,QY,TX,VS,QINN2,VSC
      QXPN2=QPURN2*60.0*XMW(6)/359.05
      QYPN2=QXPN2*0.453593
C *** ASSUME FLUIDIZING GAS IS N2,H2O, &CO2(1 MOLE CO2/1 MOLE O2 IN FEED)
      DO 150J=1,9
  150 YT(J)=0.0
      YT(6)=WINN2/WTOT
      YT(9)=WINH2O/WTOT
      YT(5)=WINO2/WTOT
      CALL VISCOS(TK,PRESA,YT,VIS)
      CALL VFMIN(VIS,RHOG,DP,XDP,PBULK,UMF)
      VRAT=VS/UMF
      UMFM=UMF*12.0*2.54
      WRITE(3,31) QXPN2,QPURN2,UMF,UMFM,QYPN2,VRAT
      IF(ISIM.EQ.2) GO TO 300
      WRITE(3,45)
      WRITE(3,32) ALAB
      WRITE(3,33)
      WRITE(3,34) TR,DELTAP,DPX,QT,DPXA
      PH2O=WINH2O*PRESA/WTOT
      ASFREE=0.0
      DO 153J=1,6
  153 ASFREE=ASFREE+APCS(J)
      PFIX=100.0-APCS(7)-APCS(8)
      DO 154J=1,6
  154 APCS(J)=APCS(J)*PFIX/ASFREE
      ADRY=0.0
      DO 155J=1,8
  155 ADRY=ADRY+APCS(J)
      TX=(TPCS-32.0)/1.8
      PSAT=10.0**(8.10765-1750.286/(TX+235.0))
      PSAT=14.696*PSAT/760.0
      YV=PSAT/(PPCS+14.696)
      APCS(9)=ADRY*YV/(1.0-YV)
      CALL YCALC(APCS,YPCS,YPCSD)
      IF(MWFC.EQ.0) GO TO 158
      XMWAVG=0.0
      DO 157J=1,9
157   XMWAVG=XMWAVG+(YPCS(J)/100.0)*XMW(J)
      QPCSV=QPCSV*SQRT(XMW(6)/XMWAVG)
  158 QPCSV=QPCSV+RLEAK+QSTV
      QPCS=QPCSV*60.0/359.05
      QPCSD=QPCS*(1.0-YPCS(9)/100.0)
      WRITE(3,35) PH2O,QPCS,QPCSV,HT,QPCSD
      XMASS=PBULKA*HT*AREA
      XMC=XMASS*0.453593
      TAUS=60.0*XMASS/QINC
      QCYCD=QPCSD
      QCYC=QCYCD/(1.0-YCYC(9)/100.0)
      QCYCM=0.453593*QCYC
      QCYCV=QCYC*359.05/60.0
      TAUG=HT/VS
      XMASSG=0.453593*XMASS
      WRITE(3,36) TAUS,QCYC,QCYCV,TAUG,QCYCD,QCYCM
      WRITE(3,37) XMASS,XMASSG
      WRITE(3,44)
      QPT=0.0
      QPMT=0.0
      DO 160J=1,9
      QP(J)=QCYC*YCYC(J)/100.0
      QPP(J)=QPCS*YPCS(J)/100.0
      QPM(J)=QP(J)*XMW(J)
      QPT=QPT+QP(J)
  160 QPMT=QPMT+QPM(J)
      QPT=QPT-QXPN2/XMW(6)-QP(9)
      QPMT1=QPMT-QXPN2-QPM(9)
      QC=12.01*(QP(2)+QP(4)+QP(5)+QP(8))
      YPCO=100.0*QP(2)/QPT
      CCONV=100.0*QC/(QINC*XULT(1))
      WRITE(3,46) YPCO,CCONV
      YCO=QPM(2)/QMAF
      PCT1=100.0*AMCH/AMCF
      PCT2=100.0*AMCYC/AMCF
      PCT3=100.0-PCT1-PCT2
      AMCG=AMCF*PCT3/100.0
      QCYCC=QCH*PCT2/PCT1
      QCHD=QCH*(1.0-XMARCH)
      QCYCCD=QCYCC*(1.0-XMARCY)
      WMCH=QCH*XMARCH/XMW(9)
      WMCY=QCYCC*XMARCY/XMW(9)
      STCONV=100.0*(WINH2O+WIMC-QP(9)-WMCH-WMCY)/WINH2O
      WRITE(3,47) YCO,STCONV
      QW=32.06*(QP(7)+QP(8))
      YPH2=100.0*QP(3)/QPT
      SCONV=100.0*QW/(QINC*XULT(4))
      YH2=QPM(3)/QMAF
      WRITE(3,48) YPH2,SCONV,YH2
      YPCH4=100.0*QP(4)/QPT
      YCH4=QPM(4)/QMAF
      WRITE(3,39) YPCH4,YCH4
      HV=QP(2)*HEATV(1)+QP(3)*HEATV(2)+QP(4)*HEATV(3)
      QMSG=QPM(2)+QPM(3)+QPM(4)+QPM(6)-QXPN2
      HV1=HV/QPMT1
      QCYCV1=QCYCV-QPURN2-QP(9)*359.05/60.0
      HV1X=HV/(60.0*QCYCV1)
      HV1Y=HV1/0.43028
      HV2=HV/QMSG
      HV2X=HV/(359.05*(QP(2)+QP(3)+QP(4)+QP(6))-60.0*QPURN2)
      HV2Y=HV2/0.43028
      WRITE(3,50) HV1,AMCF,HV1X,AMCH,PCT1
      WRITE(3,51) HV1Y,AMCYC,PCT2,AMCG,PCT3
      QGASIN=QINH2O+QX+QZ+QXPN2
      QCH1=QINC+QGASIN-QPMT-QCYCC
      WRITE(3,52) HV2,HV2X,QCH,HV2Y,QCH1
      WRITE(3,53)
      WRITE(3,54)
      DO 165J=2,8
  165 WRITE(3,55) SPEC(J),YCYC(J),YCYCD(J),QP(J),YPCS(J),YPCSD(J),QPP(J)
      WRITE(3,62) SPEC(9),YCYC(9),QP(9),YPCS(9),QPP(9)
      H2SP=YCYCD(7)*1.0E4
      COSP=YCYCD(8)*1.0E4
      WRITE(3,72) H2SP,COSP
      WRITE(3,45)
      WRITE(3,32) ALAB
      WRITE(3,68)
      WRITE(3,73)
      DO 170J=1,5
  170 QEL(1,J)=QINC*XULT(J)
      QEL(1,6)=QINC
      WRITE(3,56) QEL(1,6),QEL(1,1),QEL(1,2),QEL(1,5),QEL(1,3),QEL(1,4)
      QEL(2,1)=0.0
      QEL(2,2)=2.0*WINH2O*1.008
      QEL(2,5)=(WINH2O+2.0*WINO2)*16.0
      QEL(2,3)=WINN2*XMW(6)+QXPN2
      QEL(2,4)=0.0
      QEL(2,6)=QGASIN
      WRITE(3,57) QEL(2,6),QEL(2,1),QEL(2,2),QEL(2,5),QEL(2,3),QEL(2,4)
      DO 180J=1,6
  180 QEL(5,J)=QEL(1,J)+QEL(2,J)
      WRITE(3,58) QEL(5,6),QEL(5,1),QEL(5,2),QEL(5,5),QEL(5,3),QEL(5,4)
      DO 190J=1,5
  190 QEL(1,J)=QCH *XUCH(J)
      QEL(1,6)=QCH
      WRITE(3,59) QEL(1,6),QEL(1,1),QEL(1,2),QEL(1,5),QEL(1,3),QEL(1,4)
      DO 200J=1,5
  200 QEL(2,J)=QCYCC *XUCY(J)
      QEL(2,6)=QCYCC
      WRITE(3,60) QEL(2,6),QEL(2,1),QEL(2,2),QEL(2,5),QEL(2,3),QEL(2,4)
      QEL(3,1)=QC
      QEL(3,2)=(2.0*(QP(3)+QP(7)+QP(9))+4.0*QP(4))*1.008
      QEL(3,5)=(2.0*QP(1)+QP(2)+2.0*QP(5)+QP(8)+QP(9))*16.0
      QEL(3,3)=QP(6)*XMW(6)
      QEL(3,4)=(QP(7)+QP(8))*32.064
      QEL(3,6)=QPMT
      WRITE(3,61) QEL(3,6),QEL(3,1),QEL(3,2),QEL(3,5),QEL(3,3),QEL(3,4)
      DO 210J=1,6
  210 QEL(4,J)=0.0
      WRITE(3,63) QEL(4,6),QEL(4,1),QEL(4,2),QEL(4,5),QEL(4,3),QEL(4,4)
      DO 220J=1,6
      QEL(6,J)=QEL(1,J)+QEL(2,J)+QEL(3,J)+QEL(4,J)
  220 QEL(7,J)=100.0*QEL(6,J)/QEL(5,J)
      WRITE(3,64) QEL(6,6),QEL(6,1),QEL(6,2),QEL(6,5),QEL(6,3),QEL(6,4)
      WRITE(3,65) QEL(7,6),QEL(7,1),QEL(7,2),QEL(7,5),QEL(7,3),QEL(7,4)
  300 RETURN
      END
      SUBROUTINE YCALC(A,Y,YD)
      DIMENSION A(9),Y(9),YD(8)
      SUM=0.0
      DO 100J=1,8
  100 SUM=SUM+A(J)
      SUMT=SUM+A(9)
      DO 110J=1,8
      YD(J)=100.0*A(J)/SUM
  110 Y(J)=100.0*A(J)/SUMT
      Y(9)=100.0*A(9)/SUMT
      RETURN
      END
      SUBROUTINE XCORR(XMAR,XMOIS,XASH,XULT,QAR,INDEX)
      DIMENSION XULT(5),XLAB(3)
      DATA XLAB/'COAL','CHAR','DUST'/
      QAR=(1.0-XMOIS)/(1.0-XMAR)
      QM=QAR*XMAR
      XASH=XASH/QAR
      DO 20J=1,4
   20 XULT(J)=XULT(J)/QAR
      XULT(2)=XULT(2)-2.02*(XMOIS-QM)/(18.0*QAR)
      XMOIS=XMAR
      SUM=0.0
      DO 25J=1,4
   25 SUM=SUM+XULT(J)
      SUM=SUM+XASH
      IF(SUM-1.0) 30,30,40
   30 XULT(5)=1.0-SUM
      RETURN
   40 WRITE(3,999) XLAB(INDEX)
  999 FORMAT('0',A4,' ANALYSIS FRACTIONS SUM TO MORE THAN 1')
      STOP
      END
      SUBROUTINE VISCOS(TK,PRESA,Y,VIS)
C *** GAS VISCOSITY CALCULATION -- ALEXANDER, PP. 19-22. VIS IN MICROPOISE
C *** LUMP H2S & COS TOGETHER WITH N2
      DIMENSION V(9),Y(9)
      COMMON/BLK8/XMW(9),TC(9),PC(9),ZC(9),VC(9)
      DATA V(7)/0.0/,V(8)/0.0/
      Y6T=Y(6)
      Y7T=Y(7)
      Y8T=Y(8)
      Y(6)=Y(6)+Y(7)+Y(8)
      Y(7)=0.0
      Y(8)=0.0
      TK1=TK**2
      TK2=TK**3
      TK3=TK**4
      TK4=TK**5
C
C  CALCULATE THE INDIVIDUAL GAS VISCOSITIES
C
C
      IF(Y(9).LT.0.001) GO TO 55
C  VISCOSITY OF WATER
      V1H2O=9.65
      V2H2O=2.9347D-1*TK
      V3H2O=0.92109D-4*TK1
      V4H2O=0.41666D-7*TK2
      V(9)=V1H2O+V2H2O+V3H2O-V4H2O
C
   55 IF (Y(1).LT.0.001) GO TO 60
C  VISCOSITY OF OXYGEN
      V1O2=9.24353
      V2O2=9.41787D-1*TK
      V3O2=9.02673D-4*TK1
      V4O2=5.91612D-7*TK2
      V5O2=14.4572D-11*TK3
      V(1)=-V1O2+V2O2-V3O2+V4O2-V5O2
C
   60 IF(Y(6).LT.0.001) GO TO 65
C  VISCOSITY OF NITROGEN
      V1N2=5.2239
      V2N2=7.2345D-1*TK
      V3N2=5.8131D-4*TK1
      V4N2=3.2167D-7*TK2
      V5N2=7.0913D-11*TK3
      V(6)=V1N2+V2N2-V3N2+V4N2-V5N2
C
   65 IF(Y(2).LT.0.001) GO TO 70
C  VISCOSITY OF CARBON MONOXIDE
      V1CO=23.64
      V2CO=5.87648D-1*TK
      V3CO=2.73351D-4*TK1
      V4CO=0.655858D-7*TK2
      V(2)=V1CO+V2CO-V3CO+V4CO
C
   70 IF(Y(5).LT.0.001) GO TO 75
C  VISCOSITY OF CARBON DIOXIDE
      V1CO2=5.4384
      V2CO2=5.9427D-1*TK
      V3CO2=2.5895D-4*TK1
      V4CO2=0.64557D-7*TK2
      V(5)=-V1CO2+V2CO2-V3CO2+V4CO2
C
   75 IF(Y(4).LT.0.001) GO TO 80
C  VISCOSITY OF METHANE
      V1CH4=1.08617
      V2CH4=4.08666D-1*TK
      V3CH4=1.381078D-4*TK1
      V(4)=V1CH4+V2CH4-V3CH4
C
   80 IF(Y(3).LT.0.001) GO TO 85
C  VISCOSITY OF HYDROGEN
      V1H2=2.105
      V2H2=4.774D-1*TK
      V3H2=9.9784D-4*TK1
      V4H2=16.1827D-7*TK2
      V5H2=128.024D-11*TK3
      V6H2=38.164D-14*TK4
      V(3)=V1H2+V2H2-V3H2+V4H2-V5H2+V6H2
C
C   CALCULATE THE WILKE PARAMETERS
C
   85 CON=SQRT(8.0)
      VISTOT=0.0
      P=0.0
      DO 101I=1,9
      IF(Y(I).LT.0.001.OR.V(I).EQ.0.0) GO TO 101
      DO 102J=1,9
      IF(Y(J).LT.0.001.OR.V(J).EQ.0.0) GO TO 102
      D1=(V(I)/V(J))**0.5
      D2=(XMW(J)/XMW(I))**0.25
      D3=(1.0+D1*D2)**2
      D4=(1.0+XMW(I)/XMW(J))**0.5
      PI=D3/(CON*D4)
      PYI=PI*(Y(J)/Y(I))
      P=P+PYI
  102 CONTINUE
      VISMIX=V(I)/P
      P=0.0
      VISTOT=VISTOT+VISMIX
  101 CONTINUE
      VISO=VISTOT/10000.0
C
C   CRITICAL PROPERTIES
C
      TCT=0.0
      ZCT=0.0
      VCT=0.0
      XMT=0.0
      Y(6)=Y6T
      Y(7)=Y7T
      Y(8)=Y8T
      DO 103I=1,9
      TCT=TCT+TC(I)*Y(I)
      ZCT=ZCT+ZC(I)*Y(I)
      VCT=VCT+VC(I)*Y(I)
      XMT=XMT+XMW(I)*Y(I)
  103 CONTINUE
      PCT=ZCT*TCT*82.054/VCT
C
C  CALCULATE THE PRESSURE EFFECT ON THE GAS VISCOSITY
C
      SQCT=TCT**0.167/((XMT**0.5)*(PCT**0.667))
      TR=1.8*TK
      DEN=PRESA/(669.8*TR)
      RHOR=DEN*VCT
      E1= EXP(1.439*RHOR)
      E2= EXP(-1.111*(RHOR**1.858))
      E3=E1-E2
      E4=1.08E-4*E3
      E5=E4/SQCT
      VISPRS=VISO+E5
      VIS=6.72D-4*VISPRS
      RETURN
      END
      SUBROUTINE VFMIN(VIS,RHOG,DP,XDP,PBULK,UMF)
C *** MINIMUM FLUIDIZATION VELOCITY -- ALEXANDER,P.369
      DIMENSION DP(10),XDP(10)
      GDEN=RHOG
      A2=25.25**2
      SUM=0.0D0
      DO 10 I=1,10
      IF(DP(I).EQ.0.0.OR.XDP(I).EQ.0.0) GO TO 10
      DPE=DP(I)*3.281D-6
      A1= VIS/(GDEN*DPE)
   30 A6=PBULK-GDEN
      A3=((DPE**3)*GDEN*A6*32.174)/(VIS**2)
      A4=0.0651*A3
      A5=SQRT(A2+A4)-25.25
      UMFI=A1*A5
      SUM=SUM+XDP(I)*UMFI
   10 CONTINUE
      UMF=SUM
      RETURN
      END
      SUBROUTINE WATER
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK6/ACYC(9),APCS(9),YCYC(9),YCYCD(8),YPCS(9),YPCSD(8)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1  WINO2,WINN2,TGOUT
      COMMON/BLK11/PH,NTW,SPW(25),CWATR(25)
    1 FORMAT('0'//52X,'TRAP WATER ANALYSIS'//56X,'PH =',F6.2/)
    2 FORMAT('0',29X,'SPECIES   C(MG/LITER)   PRODUCTION RATE IN GASIFIE
     1R',5X,'LB PRODUCED/LB COAL FED'//58X,'LB/HR',8X,'MG/HR'/)
    3 FORMAT(32X,A4,5X,F8.2, 6X,1PE9.2,5X,E9.2,10X,E9.2)
      WRITE(3,1) PH
      IF(NTW.EQ.0) RETURN
      WRITE(3,2)
      FACT=0.08172*QCYC*YCYC(9)
      DO 100J=1,NTW
      QWPR=FACT*CWATR(J)
      QW=QWPR/453593.0
      QRAT=QW/QINC
      WRITE(3,3) SPW(J),CWATR(J),QW,QWPR,QRAT
  100 CONTINUE
      RETURN
      END
      SUBROUTINE TRACE
      DIMENSION XTC(20),XTCH(20),XTCYD(20),XTW(20),XTG(20),QTC(20),
     1QTCH(20),QTCYD(20),FTCYG1(20),FTCYG2(20),QTCYG1(20),QTCYG2(20),
     2FTCYGT(20),QTCYGT(20),TOUT(20),PDIFF(20),ERCH(20),ERCYD(20),
     3ERG(20),CTCYG1(20),CTCYG2(20)
      COMMON/BLK1/ALAB(20),ALABC(15),ISIM,PRES,TR,HT,DIAM,RLEAK,PDEN,
     1 PBULK
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK4/IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS,QPURN2
     1,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,PINN2
      COMMON/BLK6/ACYC(9),APCS(9),YCYC(9),YCYCD(8),YPCS(9),YPCSD(8)
      COMMON/BLK7/XMARCH,XMCH,XASHCH,XVOLCH,XUCH(5),XMARCY,XMCY,XASHCY,
     1 XVOLCY,XUCY(5)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1 WINO2,WINN2,TGOUT
      COMMON/BLK10/NT,TNAM(20),CTC(20),CTCH(20),CTCYD(20),CTW(20),
     1 CMW(20),CTG(20),QEL(7,6)
    1 FORMAT(///50X,'TRACE ELEMENT ANALYSIS: PPM'//22X,'ELEMENT',8X,
     1 'IN COAL',8X,'IN CHAR',8X,'IN DUST',8X,'IN WATER',8X,'IN GAS'/)
    2 FORMAT(24X,A4,6X,1PE11.3,4X,4(E11.3,4X))
    3 FORMAT(///44X,'TRACE ELEMENT MATERIAL BALANCE: FLOWS IN LB/HR'//
     1 40X,'IN',25X,'OUT'//20X,'ELEMENT',12X,'COAL',12X,'CHAR',8X,
     2 'DUST',8X,'GAS',8X,'TOTAL OUT',4X,'% RECOVERY'/)
    4 FORMAT('1'//16X,20A4)
    5 FORMAT(22X,A4,9X,1PE10.3,6X,2(E10.3,2X),E10.3,4X,E10.3,4X,
     1 0PF7.1,'%')
    6 FORMAT(////)
    7 FORMAT(///42X,'TRACE ELEMENT ENRICHMENT RATIOS;REFERENCE ASH CONT
     1ENT'//,49X,'ELEMENT',10X,'CHAR',12X,'DUST')
    8 FORMAT(51X,A4,6X,1PE11.3,5X,E11.3,)
      WRITE(3,4) ALAB
      DO 100 J=1,NT
      XTC(J)= CTC(J)*1.0E-6
      XTCH(J)= CTCH(J)*1.0E-6
      XTCYD(J)= CTCYD(J)*1.0E-6
      XTG(J)=CTG(J)*1.0E-06
  100 XTW(J)= CTW(J)*1.0E-6
      FRAC1= YCYC(9)*18.0152/100.0
      FRAC2= 1.0-YCYC(9)/100.0
      DO 200 J=1,NT
      QTC(J)= XTC(J)*QINC
      QTCH(J)= XTCH(J)*QCH
      QTCYD(J)= XTCYD(J)*QCYCC
      FTCYG1(J)= XTW(J)*FRAC1
      QTCYG1(J)= FTCYG1(J)*QCYC*2.204E-3
      FTCYG2(J)=XTG(J)*359.0*FRAC2
      QTCYG2(J)=FTCYG2(J)*QCYC*2.204E-3
      CTCYG2(J)=FTCYG2(J)/CMW(J)*1.0E6
      FTCYGT(J)=FTCYG1(J)+FTCYG2(J)
      QTCYGT(J)=QTCYG1(J)+QTCYG2(J)
      TOUT(J)= QTCH(J)+QTCYD(J)+QTCYGT(J)
  200 PDIFF(J)=100.0*TOUT(J)/QTC(J)
      DO 300 J=1,NT
      ERCH(J)=(QTCH(J)*XASH*QINC)/(QTC(J)*XASHCH*QCH)
      ERCYD(J)=(QTCYD(J)*XASH*QINC)/(QTC(J)*XASHCY*QCH)
  300 CONTINUE
      WRITE(3,1)
      DO 400 J=1,NT
      WRITE(3,2)  TNAM(J),CTC(J),CTCH(J),CTCYD(J),CTW(J),CTCYG2(J)
  400 CONTINUE
      WRITE (3,6)
      WRITE(3,3)
      DO 500 J=1,NT
      WRITE(3,5)  TNAM(J),QTC(J),QTCH(J),QTCYD(J),QTCYGT(J),TOUT(J),
     1 PDIFF(J)
  500 CONTINUE
```

```
      WRITE(3,6)
      WRITE(3,7)
      DO 600 J=1,NT
      WRITE(3,8)TNAM(J),ERCH(J),ERCYD(J)
  600 CONTINUE
      RETURN
      END
      SUBROUTINE ENERGY
      DIMENSION A(9),B(9),C(9),D(9),HF(9)
      COMMON/BLK1/ALAB(20),ALABC(15),ISIM,PRES,TR,HT,DIAM,RLEAK,PDEN,
     1 PBULK
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK4/IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS,QPURN2
     1,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,PINN2
      COMMON/BLK7/XMARCH,XMCH,XASHCH,XVOLCH,XUCH(5),XMARCY,XMCY,XASHCY,
     1 XVOLCY,XUCY(5)
      COMMON/BLK8/XMW(9),TC(9),PC(9),ZC(9),VC(9)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1 WINO2,WINN2,TGOUT
C *** SUBSCRIPT KEY : 1=O2,2=CO,3=H2,4=CH4,5=CO2,6=N2,7=H2S,8=COS,9=H2O
      DATA AIN/0.0164/,AOUT/0.0218/
      DATA HF/0.0,-4.755E04,0.0,-3.221E04,-1.693E05,0.0,-8.588E03,
     %-6.090E04,-1.0405E05/
      DATA HFH2O/-1.0405E05/,HFSO2/-1.277E05/
      DATA A/6.955,6.919,6.893,8.200,8.630,6.931,8.009,5.629,7.997/
      DATA B/2.768E-03,9.823E-04,1.828E-05,1.307E-02,1.012E-02,5.256E-04
     %,3.697E-03,1.907E-02,1.644E-03/
      DATA C/-1.452E-06,8.480E-07,7.859E-07,8.750E-07,-6.900E-06,1.368E-
     %06,7.199E-07,-1.676E-05,1.817E-06/
      DATA D/3.133E-10,-5.306E-10,-2.079E-10,-2.629E-09,1.784E-09,-6.862
     %E-10,-7.868E-10,5.860E-09,-8.587E-10/
    2 FORMAT('0',22X,'COAL IN    =',F7.1,' DEG.F',T70,'ENERGY IN    =',1PE
     1 10.2,' BTU/HR (',E10.2,' KJ/HR)')
    3 FORMAT(23X,'GASES IN  =',F7.1,' DEG.F',T70,'ENERGY OUT  =',1PE10.2
     1,' BTU/HR (',E10.2,' KJ/HR)')
    4 FORMAT(T70,'HEAT LOSS    =',1PE10.2,' BTU/HR (',E10.2,' KJ/HR)')
    6 FORMAT(23X,'CHAR OUT  =',F7.1,' DEG.F')
    7 FORMAT(/'0',19X,'FEED AND EFFLUENT TEMPERATURES',T87,'ENERGY BALAN
     1CE'/)
    8 FORMAT(23X,'GASES OUT =',F7.1,' DEG.F',T70,'% HEAT LOSS =',F6.1,
     1'%')
C
      WRITE(3,7)
C     ***CALCULATE KINETIC ENERGY OF FEED GASES***
C **  LUMP PURGE N2 IN WITH OTHER FEED GASES
      TINA=TIN+459.69
      PATM=(PRES+14.696)/14.696
      WPN2=QPURN2*60.0/359.05
      VSIN=WTOT*359.05*(TINA/491.69)*(1.0/PATM)/(3600.0*AIN)
      EKIN=QGASIN*VSIN**2/(2.0*32.174)*1.2861E-03
C     ***CALCULATE ENTHALPY OF FEED STREAMS***
      HTVC=14544.*XULT(1)+62028.*(XULT(2)-0.125*XULT(5))+4050.*XULT(4)
      HFCOAL=XULT(1)/12.01*HF(5)+XULT(2)/2.016*HFH2O+XULT(4)/32.064*HFSO
     %2+HTVC
      HINC=QINC*(HFCOAL+0.25*(TINC-77.0))
      HINH2O=WINH2O*(HF(9)+DELCP(A(9),B(9),C(9),D(9),TIN))
      HINO2=WINO2*DELCP(A(1),B(1),C(1),D(1),TIN)
      HINN2=WINN2*DELCP(A(6),B(6),C(6),D(6),TIN)
      HINPN2=WPN2*DELCP(A(6),B(6),C(6),D(6),TINPN2)
      HIN=HINC+HINH2O+HINO2+HINN2+HINPN2
      EIN=EKIN+HIN
      EINM=EIN/0.9486
      WRITE(3,2) TINC,EIN,EINM
C
C     ***CALCULATE KINETIC ENERGY OF PRODUCT GAS***
      TRA=TGOUT+459.69
      VSOUT=QCYC*359.05*(TRA/491.69)*(1.0/PATM)/(3600.*AOUT)
      EKOUT=QPMT*VSOUT**2/(2.*32.174)*1.2861E-03
C     ***CALCULATE ENTHALPY OF PRODUCT STREAMS***
      HTVCH=14544.*XUCH(1)+62028.*(XUCH(2)-0.125*XUCH(5))+4050.*XUCH(4)
      HFCH=XUCH(1)/12.01*HF(5)+XUCH(2)/2.016*HFH2O+XUCH(4)/32.064*HFSO2+
     %HTVCH
      HOUTCH=QCH*(HFCH+0.25*(TR-77.))
      HTVCYC=14544.*XUCY(1)+62028.*(XUCY(2)-0.125*XUCY(5))+4050.*XUCY(4)
      HFCYCC=XUCY(1)/12.01*HF(5)+XUCY(2)/2.016*HFH2O+XUCY(4)/32.064*HFSO
     %2+HTVCYC
      HOUTCY=QCYCC*(HFCYCC+0.25*(TGOUT-77.0))
      HOUTG=0.0
      DO 100 J=2,9
      HOUTG=HOUTG+QP(J)*(HF(J)+DELCP(A(J),B(J),C(J),D(J),TGOUT))
  100 CONTINUE
      HOUT=HOUTCH+HOUTCY+HOUTG
C
      EOUT=EKOUT+HOUT
      EOUTM=EOUT/0.9486
      WRITE(3,3) TIN,EOUT,EOUTM
      DE=EIN-EOUT
      DEM=DE/0.9486
      WRITE(3,4) DE,DEM
      WRITE(3,6) TR
      DEP=100.0*DE/ABS(EIN)
      WRITE(3,8) TGOUT,DEP
      RETURN
      END
      FUNCTION DELCP(A,B,C,D,T)
C *** CALCULATE DELTA-H(BTU/LB-MOLE) FOR TRANSITION FROM 77 DEG.F TO T(DEG.F)
C *** CP(CAL/G-DEG.C) = A+B*TC+C*TC**2+D*TC**3, WHERE TC IS IN DEG.C
      TC=(T-32.0)/1.8
      DELCP=A*(TC-25.0)+B*(TC**2-25.0**2)/2.0+C*(TC**3-25.0**3)/3.0+D*
     1 (TC**4-25.0**4)/4.0
      DELCP=DELCP*1.8
      RETURN
      END
      SUBROUTINE GPLOT
C *** GRAPHICAL DISPLAY OF GASIFIER LOG DATA
C *** PROGRAM WRITTEN BY J.C.MCCUE
      COMMON/BLK1/ALAB(20),ALABC(15),ISIM,PRES,TR,HT,DIAM,RLEAK,PDEN,
     1 PBULK
      COMMON/BLK2/XMAR,XMOIS,XASH,XVOLA,XFIXA,XULT(5),DP(10),XDP(10)
      COMMON/BLK3/QINC,QINH2O,QINO2,QINN2,TINC,TIN
      COMMON/BLK4/IEXH,AMCF,AMCH,AMCYC,QCH,DELTAP,QPCSV,TPCS,PPCS,QPURN2
     1,TINPN2,PINPN2,TINH2O,PINH2O,TINO2,PINO2,TINN2,PINN2
      COMMON/BLK6/ACYC(9),APCS(9),YCYC(9),YCYCD(8),YPCS(9),YPCSD(8)
      COMMON/BLK7/XMARCH,XMCH,XASHCH,XVOLCH,XUCH(5),XMARCY,XMCY,XASHCY,
     1 XVOLCY,XUCY(5)
      COMMON/BLK9/WTOT,HTVC,HTVCH,QCYC,QCYCC,QP(9),QPMT,QGASIN,WINH2O,
     1  WINO2,WINN2,TGOUT
      COMMON/BLK12/TRP(7),IHB(7),QSCRUB,DPT232,TT234,PCSWT,PCSWL,PCSWV,
     1  QS,QT,H2SP,COSP,CCONV,XMASS
      WRITE(3,999)
  999 FORMAT('1')
      WRITE(3,998) ALAB
  998 FORMAT('0',40X,43('*')/41X,'*',41X,'*'/41X,'* NCSU DEPARTMENT OF C
     1HEMICAL ENGINEERING *'/41X,'*',41X,'*'/41X,'* FLUIDIZED BED COAL G
     2ASIFICATION REACTOR *'/41X,'*',41X,'*'/41X,43('*')///16X,20A4)
      QSV=0.40*QSCRUB
      PCSWV=(PCSWL+16.0)*52.89/12.0
      WRITE(3,1) QINC
    1 FORMAT('0'//25X,'COAL FEED',31X,5('*')/25X,F4.1,' LB/HR',17X,
     1 'GAS OUTPUT',3X,'*',3X,'*')
      WRITE(3,2)
    2 FORMAT(24X,19('-'),'>',4X,':',15('-'),'>*',3X,'*',20('-'),'>:')
      ITR=TRP(7)
      WRITE(3,3) XULT(1),ITR
    3 FORMAT(25X,F6.4,' C',10X,':',4X,':',3X,'T =',I5,' F',3X,'*',3X,
     1 '*',21X,':')
      WRITE(3,4) XULT(2),YCYC(9)
    4 FORMAT(25X,F6.4,' H',10X,':',4X,':',3X,F4.1,'% H2O',4X,'*',3X,
     1 '*',21X,':')
      WRITE(3,5) XULT(5)
    5 FORMAT(25X,F6.4,' O',10X,':',4X,':',16X,5('*'),15X,':',4('-'),
     1 '>:')
      WRITE(3,6) XULT(3)
    6 FORMAT(25X,F6.4,' N',10X,'V',4X,':',15X,'CYCLONE',14X,':',5X,':')
      WRITE(3,7) XULT(4)
    7 FORMAT(25X,F6.4,' S',5X,17('*'),30X,':',5X,':')
      WRITE(3,8) XASH
    8 FORMAT(25X,F6.4,' ASH',3X,'*',15X,'*',30X,':',4X,'):( VENTURI SCRU
     1BBER')
      ITR=IT234
      WRITE(3,9) DPT232,ITR
    9 FORMAT(38X,'*',3X,'GASIFIER',4X,'*',24X,'SCRUB :',5X,':  DP =',
     1 F4.1,' IN.H2O'/38X,'*',5X,'TEMP.',5X,'*',24X,'WATER :',5X,':  T(O
     2UT) =',I4,' F')
      WRITE(3,10) QSV
   10 FORMAT(38X,'*',4X,'PROFILE',4X,'*',30X,':',5X,':'/38X,'*',15X,
     1 '*',20X,F5.1,' GPH :',5X,':'/38X,'*',15X,'*',30X,':',5X,':',15X,
     2 'SOUR GAS')
      WRITE(3,11)
   11 FORMAT(38X,'*',15X,'*',30X,':',5X,':',8X,':',17('-'),'>')
      ITR=TRP(6)
      WRITE(3,12) IHB(6),ITR,QPCSV
   12 FORMAT(38X,'*',I3,2H'',1X,I6,' F *',30X,':',5X,':',8X,':',5X,
     1F5.1,' SCFM')
      WRITE(3,13) TPCS,PPCS
   13 FORMAT(38X,'*',15X,'*',30X,':',5X,':',8X,':',5X,F5.1,' F'/38X,
     1'*',15X,'*',30X,':',5X,'V',8X,':',5X,F5.1,' PSIG')
      ITR=TRP(5)
      WRITE(3,14) IHB(5),ITR
   14 FORMAT(38X,'*',I3,2H'',1X,I6,' F *',6X,'GASIFIER',16X,':',3X,
     1 14('*'))
      WRITE(3,15) YPCS(2)
   15 FORMAT(38X,'*',15X,'*',30X,':',3X,'*',12X,'*',3X,F5.1,'% CO')
      ITR=TR
      WRITE(3,16) ITR,YPCS(3)
   16 FORMAT(38X,'*',15X,'*',2X,'T(AV) =',I6,' F',T86,':',3X,'*',12X,
     1 '*',3X,F5.1,'% H2')
      ITR=TRP(4)
      WRITE(3,17) IHB(4),ITR,PRES,YPCS(4)
   17 FORMAT(38X,'*',I3,2H'',1X,I6,' F *',2X,'P(AV) =',F6.1,' PSIG',T86,
     1':',3X,'*',12X,'*',3X,F5.1,'% CH4')
      HTI=HT*12.0
      WRITE(3,18) HTI,YPCS(5)
   18 FORMAT(38X,'*',15X,'*',2X,'BED LEVEL    =',F5.1,' IN' ,T86,':',3X,
     1'*',12X,'*',3X,F5.1,'% CO2')
      WRITE(3,19) XMASS,YPCS(6)
   19 FORMAT(38X,'*',15X,'*',2X,'SOLID HOLDUP =',F5.1,' LB',T86,':',3X,
     1'*',12X,'*',3X,F5.1,'% N2')
      ITR=TRP(3)
      ITR1=PCSWT
      WRITE(3,20) IHB(3),ITR,ITR1,YPCS(9),CCONV
   20 FORMAT(38X,'*',I3,2H'',1X,I6,' F *',30X,':',3X,'* T =',I4,' F  *'
     1 ,3X,F5.1,'% H2O'/38X,'*',15X,'*',2X,'C CONVERSION =',F5.1,'%',
     2 8X,':',3X,'*',12X,'*')
      IPCSV=PCSWV
      IH2SP=H2SP
      WRITE(3,21) IPCSV,IH2SP
   21 FORMAT(38X,'*',15X,'*',30X,':',3X,'* V =',I4,' GAL*',3X,I6,
     1 ' PPM H2S')
      ITR=TRP(2)
      ICOSP=COSP
      WRITE(3,22) IHB(2),ITR,ICOSP
   22 FORMAT(38X,'*',I3,2H'',1X,I6,' F *',30X,':',3X,'*',12X,'*',3X,
     1 I6,' PPM COS')
      WRITE(3,23)
   23 FORMAT(38X,'*',15X,'*',30X,':',3X,'*',12X,'*')
      WRITE(3,23)
      ITR=TRP(1)
      WRITE(3,24) IHB(1),ITR
   24 FORMAT(38X,'*',I3,2H'',1X,I6,' F *',30X,'<---*',12X,'*')
      WRITE(3,25)
   25 FORMAT(38X,'*',15X,'*',34X,'*',12X,'*')
      WRITE(3,26)
   26 FORMAT(38X,17('*'),34X,14('*'))
      WRITE(3,27)
   27 FORMAT(43X,':',4X,':',43X,'PCS TANK'/43X,':',4X,':')
      WRITE(3,28) QCH
   28 FORMAT(25X,'CHAR REMOVAL',6X,':',4X,':'/25X,F4.1,' LB/HR',8X,
     1 ':',4X,':   GAS FEED')
      WRITE(3,29)
   29 FORMAT(24X,'<',18('-'),':',4X,'<',24('-'))
      WRITE(3,30) XUCH(1),QINH2O
   30 FORMAT(25X,F6.4,' C',18X,F5.1,' LB/HR H2O')
      WRITE(3,31) XUCH(2),QINO2,XUCH(5),QINN2
   31 FORMAT(25X,F6.4,' H',18X,F5.2,' SCFM O2'/25X,F6.4,' O',18X,F5.2,
     1 ' SCFM N2')
      WRITE(3,32) XUCH(3),XUCH(4),QS
   32 FORMAT(25X,F6.4,' N'/25X,F6.4,' S',18X,F5.2,' MOLES H2O/MOLE C')
      WRITE(3,33) XASHCH,QT
   33 FORMAT(25X,F6.4,' ASH',16X,F5.2,' MOLES N2/MOLE O2')
      RETURN
      END
```

APPENDIX D

```
                    ******************************************
                    *                                        *
                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                        *
                    *      ACID   GAS   REMOVAL   SYSTEM     *
                    *                                        *
                    ******************************************

                              RUN NUMBER A-M-30
                               INTEGRATED
                              DATE    5/28/1980

                           STREAM COMPOSITION (MOL %)
                           ------ -----------

                                                              *        *        *
           SOUR     SWEET    FLASH    STRIP     ACID    ABSORB    FLASH    STRIP
            GAS      GAS      GAS      N2        GAS     EXIT      EXIT     EXIT

  CO2     24.600    1.460   43.200    0.000   70.530    5.918    5.545    0.000
  H2S      0.910    0.048    0.634    0.000    2.539    0.220    0.216    0.000
  COS      0.042    0.003    0.043    0.000    0.117    0.010    0.010    0.000
  MEOH     0.000    0.000    0.000    0.000    1.320   92.764   93.669   99.393
  H2      33.170   43.190   15.240    0.000    0.000    0.619    0.473    0.502
  CO      21.060   28.480   22.720    0.000    0.980    0.204    0.000    0.000
  N2      18.500   24.890   14.750  100.000   23.580    0.202    0.057    0.105
  CH4      1.640    1.950    3.400    0.000    0.400    0.064    0.030    0.000
  C2H4     0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
  C2H6     0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000

                                   *
                                    CALCULATED


                           MASS BALANCE (LB-MOLES/HR)
                           ---- -------

              IN                    OUT
              --                    ---
                                                             *        *
        SOUR     STRIP      SWEET    FLASH    ACID       TOTAL    TOTAL    % RECOVERY
        GAS      N2         GAS      GAS      GAS        IN       OUT

CO2     0.554    0.000      0.023    0.038    0.534      0.554    0.595      107.4
H2S     0.020    0.000      0.001    0.001    0.019      0.020    0.021      100.2
COS     0.001    0.000      0.000    0.000    0.001      0.001    0.001      102.3
MEOH    0.000    0.000      0.000    0.000    0.010      0.000    0.000        0.0
H2      0.747    0.000      0.692    0.013    0.000      0.747    0.705       94.4
CO      0.474    0.000      0.456    0.020    0.007      0.474    0.484      101.9
N2      0.417    0.182      0.399    0.013    0.178      0.599    0.590       98.5
CH4     0.037    0.000      0.031    0.003    0.003      0.037    0.037      100.9
C2H4    0.000    0.000      0.000    0.000    0.000      0.000    0.000        0.0
C2H6    0.000    0.000      0.000    0.000    0.000      0.000    0.000        0.0

TOTAL   2.253    0.182      1.602    0.089    0.757      2.433    2.433      100.0
(LB-MOLES/HR)

                            *
                             METHANOL-FREE BASIS

          TOTAL METHANOL LOSS=  0.010 LB-MOLES/HR =  0.048 GALLONS/HR
```

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                                                RUN NUMBER A-M-30
                                                  INTEGRATED
                                                 DATE    5/28/1980

                                     COLUMN TEMPERATURE PROFILES & MASS BALANCES
                                     ------ ----------- -------- - ---- --------


                  ABSORBER                           FLASH TANK                        STRIPPER

                  P=397.19 PSIG                      P= 96.75 PSIG                     P=  9.85 PSIG


                       ,---> SWEET                        ,---> FLASH                       ,---> ACID
                       :     GAS                          :     GAS                         :     GAS
                       :                                  :                                 :
                       :                                  :                                 :
                       :                                  :                                 :
                  9.58 SCFM                          0.53 SCFM                         4.53 SCFM
                       :                                  :                                 :
                       :                                  :                                 :
                       :                                  :                                 :
                  **********                              :                            **********
                  *        *                              :                            *        *
    MEOH FLOW     *        *                              :                            *        *
  --- 0.66 GPM -->*        *                              :              ,-- 0.66 GPM -*        *
      (-34.13  F) *        *                              :              :   (35.96 F) *        *
                  *        *                              :              :             *        *
                  *        *                         **********          :             *        *
                  * XXXXXX *                         *        *          :             * 16.05 F*
                  *        *                         *        *          :             *        *
                  * XXXXXX *                         *        *          :             * 14.86 F*
                  *        *                         *        *          :             *        *
                  *        *                         *        *          :             *        *
                  *        *                         * 12.94 F*          :             *        *
                  *        *                         *        *          :             *        *
                  * XXXXXX *                         *        *          :             * 13.89 F*
                  *        *            .----------->*        *          :             *        *
                  * XXXXXX *            :            *        *          :             * 18.63 F*
                  *        *            :            *        *          :             *        *
                  *        *            :            *        *          :             *        *
                  *        *            :            *        *          :             *        *
                  *        *            :            *        *          :             *        *
                  *-29.63 F*            :            *        *          :             * 19.21 F*
                  *        *            :            *        *----------->            *        *
                  *-31.77 F*            :            *        *                        * 19.26 F*
                  *        *            :            **********                        *        *
                  *        *            :                                              *        *
     SOUR GAS     *        *            :                                              *        *
 -- 13.48 SCFM -->*        *            :                  STRIPPING N2-- 1.09 SCFM -->*        *
     ( 54.04 F)   *        *            :                                 (75.00 F)    *        *
                  *  4.83 F*            :                                              * 38.06 F*
                  *        *------------>                                              *        *
                  *        *                                                           *        *
                  *        *                                                           *        *
                  *        *                                                           *        *
                  **********                                                           **********
                                                                                              :
                                                                                              :
                                                                                              :
                                                                         <----TO ABSORBER-----
```

```
                                   RUN NUMBER A-M-30
                                     INTEGRATED
                                    DATE    5/28/1980
                                COLUMN TEMPERATURE PROFILE
                                ------ ----------- -------

                                           .--------> SWEET GAS
                                           :          9.58 SCFM
                                           :
                                           :
                                           :
                                           :
                                *********************
                   MEOH FLOW    *                   *
                    0.660 GPM   *                   *
                   -34.13 F     *                   *
                 -------------->*                   *
                                *                   *
                                *===================*----   7.10 FT
                                *                   *
                                *                   *
                                *                   *
                                *                   *
                                *                   *
                                *     -29.63 F      *----   4.79 FT
ABSORBER PRESSURE =397.2 PSIG   *                   *
                                *                   *
TOTAL PACKING HEIGHT= 7.10 FEET *                   *
                                *                   *
PACKING: 1/4" INTALOX SADDLES   *                   *
                                *                   *
                                *     -31.77 F      *----   2.46 FT
                                *                   *
                                *                   *
                                *                   *
                                *     -28.27 F      *----   1.21 FT
                                *                   *
                                *                   *
                                *                   *
                                *     -21.50 F      *----   0.79 FT
                                *                   *
                                *                   *
                                *                   *
                                *     -14.11 F      *----   0.31 FT
                                *                   *
                                *===================*----   0.00 FT
                                *                   *
          --------------------->*                   *
             SOUR GAS INLET     *                   *
             13.48 SCFM         *                   *
             54.04 F            *      4.83 F       *
                                *                   *-------------->
                                *********************

                                    SOUR GAS (MOL %)          SWEET GAS (MOL %)
                                    ---- ---                  ----- ---

                CO2                    24.6000                    1.4600
                H2S                     0.9096                    0.0476
                COS                     0.0423                    0.0032
                MEOH                    0.0000                    0.0000
                H2                     33.1700                   43.1900
                CO                     21.0600                   28.4800
                N2                     18.5000                   24.8900
                CH4                     1.6400                    1.9500
                C2H4                    0.0000                    0.0000
                C2H6                    0.0000                    0.0000
```

```
                    *******************************************
                    *                                         *
                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                         *
                    *       ACID   GAS   REMOVAL   SYSTEM     *
                    *                                         *
                    *******************************************

                               RUN NUMBER A-M-35
                                INTEGRATED RUN
                               DATE    6/26/1980

                            STREAM COMPOSITION (MOL %)
                            ------ -----------

                                                            *         *         *
           SOUR     SWEET     FLASH     STRIP     ACID     ABSORB     FLASH     STRIP
           GAS      GAS       GAS       N2        GAS      EXIT       EXIT      EXIT

  CO2     28.010    0.950    43.810     0.000    73.170     5.674     5.346     0.000
  H2S      0.807    0.037     0.526     0.000     1.970     0.162     0.159     0.013
  COS      0.045    0.003     0.038     0.000     0.127     0.009     0.009     0.000
  MEOH     0.000    0.000     0.000     0.000     1.200    93.934    94.453    99.973
  H2      33.190   45.500    12.880     0.000     0.000     0.118     0.013     0.014
  CO      20.200   27.850    24.590     0.000     1.660     0.048     0.000     0.000
  N2      15.700   23.230    13.920   100.000    21.120     0.000     0.000     0.000
  CH4      2.010    2.440     4.240     0.000     0.700     0.054     0.020     0.000
  C2H4     0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.000
  C2H6     0.000    0.000     0.000     0.000     0.000     0.000     0.000     0.000

                                     *
                                      CALCULATED


                            MASS BALANCE (LB-MOLES/HR)
                            ---- -------


            IN                      OUT
            --                      ---

                                                                *          *
        SOUR     STRIP         SWEET     FLASH     ACID          TOTAL      TOTAL      % RECOVERY
        GAS      N2            GAS       GAS       GAS           IN         OUT

CO2     0.618    0.000         0.015     0.038     0.575         0.618      0.628        101.7
H2S     0.018    0.000         0.001     0.000     0.015         0.018      0.017         92.9
COS     0.001    0.000         0.000     0.000     0.001         0.001      0.001        109.4
MEOH    0.000    0.000         0.000     0.000     0.009         0.000      0.000          0.0
H2      0.732    0.000         0.719     0.011     0.000         0.732      0.730         99.8
CO      0.445    0.000         0.440     0.021     0.013         0.445      0.475        106.6
N2      0.346    0.182         0.367     0.012     0.166         0.528      0.545        103.2
CH4     0.044    0.000         0.039     0.004     0.006         0.044      0.048        107.7
C2H4    0.000    0.000         0.000     0.000     0.000         0.000      0.000          0.0
C2H6    0.000    0.000         0.000     0.000     0.000         0.000      0.000          0.0

TOTAL   2.205    0.182         1.581     0.087     0.787         2.386      2.444        102.4
(LB-MOLES/HR)

                              *
                               METHANOL-FREE BASIS

          TOTAL METHANOL LOSS=  0.009 LB-MOLES/HR =  0.045 GALLONS/HR
```

```
                                    RUN NUMBER A-M-35
                                      INTEGRATED RUN
                                    DATE     6/26/1980

                                COLUMN TEMPERATURE PROFILES & MASS BALANCES
                                ------ ----------- -------- - ---- --------

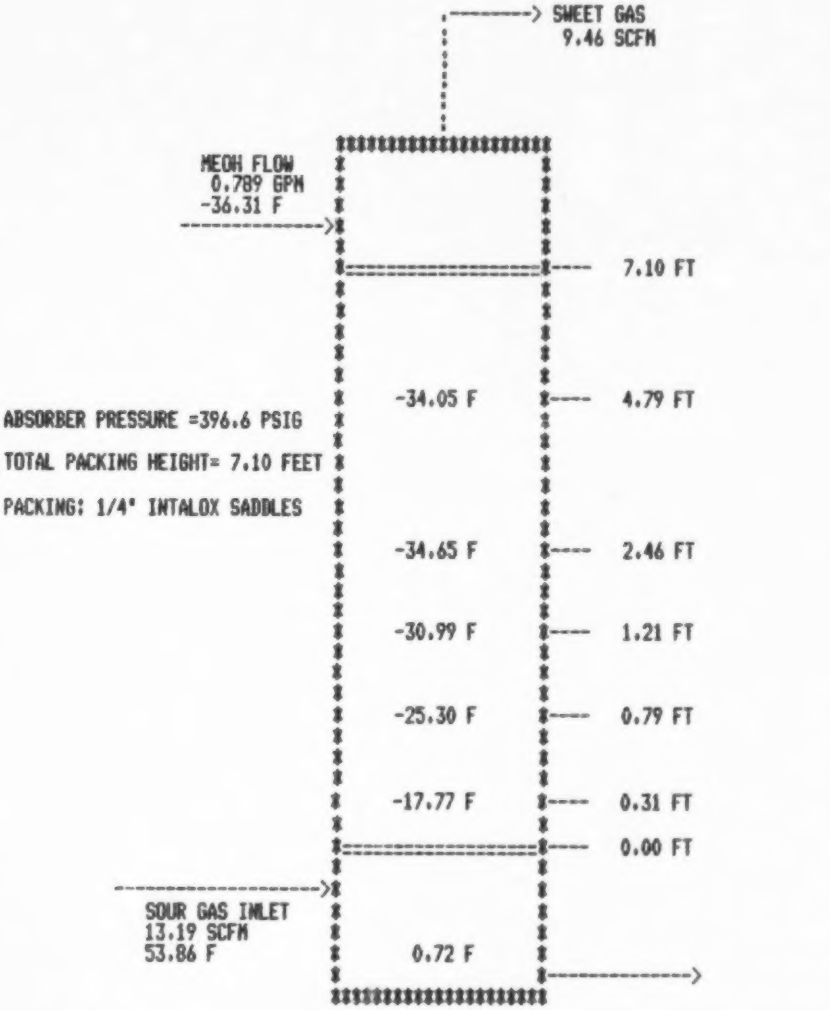
                  ABSORBER                           FLASH TANK                         STRIPPER

                  P=396.61 PSIG                      P= 96.75 PSIG                      P=  9.87 PSIG

                      ,---> SWEET                        ,---> FLASH                        ,---> ACID
                      :     GAS                          :     GAS                          :     GAS
                      :                                  :                                  :
                      :                                  :                                  :
                      :                                  :                                  :
                  9.46 SCFM                          0.52 SCFM                          4.71 SCFM
                      :                                  :                                  :
                      :                                  :                                  :
                      :                                  :                                  :
                 **********                              :                              **********
                 *        *                              :                              *        *
    MEOH FLOW    *        *                              :                              *        *
 --- 0.79 GPM -->*        *                              :               ,-- 0.79 GPM -*        *
   (-36.31  F)   *        *                              :               :   (33.06 F) *        *
                 *        *                              :               :             *        *
                 *        *                         **********           :             *        *
                 * XXXXXX *                         *        *           :             * 13.65 F*
                 *        *                         *        *           :             *        *
                 * XXXXXX *                         *        *           :             * 12.31 F*
                 *        *                         *        *           :             *        *
                 *        *                         *        *           :             *        *
                 *        *                         *  9.51 F*           :             *        *
                 *        *                         *        *           :             *        *
                 * XXXXXX *                         *        *           :             * 11.05 F*
                 *        *            .----------->*        *           :             *        *
                 * XXXXXX *            :            *        *           :             * 16.13 F*
                 *        *            :            *        *           :             *        *
                 *        *            :            *        *           :             *        *
                 *        *            :            *        *           :             *        *
                 *        *            :            *        *           :             *        *
                 *-34.05 F*            :            *        *           :             * 16.08 F*
                 *        *            :            *        *------------>            *        *
                 *-34.65 F*            :            *        *                         * 16.12 F*
                 *        *            :            **********                         *        *
                 *        *            :                                               *        *
    SOUR GAS     *        *            :                                               *        *
-- 13.19 SCFM -->*        *            :                    STRIPPING N2-- 1.09 SCFM -->*        *
  ( 53.86 F)     *        *            :                                  (75.00 F)    *        *
                 *   0.72 F*           :                                               * 33.15 F*
                 *        *------------>                                               *        *
                 *        *                                                            *        *
                 *        *                                                            *        *
                 *        *                                                            *        *
                 **********                                                            **********
                                                                                            :
                                                                                            :
                                                                                            :
                                                                        <----TO ABSORBER-----
```

```
RUN NUMBER A-M-35
 INTEGRATED RUN
DATE    6/26/1980

COLUMN TEMPERATURE PROFILE
------ ----------- -------
```



SWEET GAS
9.46 SCFM
MEOH FLOW
0.789 GPM
-36.31 F
7.10 FT
-34.05 F
4.79 FT
ABSORBER PRESSURE =396.6 PSIG
TOTAL PACKING HEIGHT= 7.10 FEET
PACKING: 1/4" INTALOX SADDLES
-34.65 F
2.46 FT
-30.99 F
1.21 FT
-25.30 F
0.79 FT
-17.77 F
0.31 FT
0.00 FT
SOUR GAS INLET
13.19 SCFM
53.86 F
0.72 F

```
                   SOUR GAS (MOL %)       SWEET GAS (MOL %)
                   ---- ---               ----- ---

CO2                   28.0100                 0.9500
H2S                    0.8072                 0.0371
COS                    0.0450                 0.0034
MEOH                   0.0000                 0.0000
H2                    33.1900                45.5000
CO                    20.2000                27.8500
N2                    15.7000                23.2300
CH4                    2.0100                 2.4400
C2H4                   0.0000                 0.0000
C2H6                   0.0000                 0.0000
```

```
                    *************************************
                    *                                   *
                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                   *
                    *      ACID   GAS   REMOVAL   SYSTEM      *
                    *                                   *
                    *************************************

                              RUN NUMBER A-M-36
                               INTEGRATED RUN
                              DATE    7/18/1980

                         STREAM COMPOSITION (MOL %)
                         ------ -----------
                                                             *        *        *
             SOUR     SWEET    FLASH    STRIP    ACID    ABSORB   FLASH    STRIP
             GAS      GAS      GAS      N2       GAS     EXIT     EXIT     EXIT

      CO2   20.900    0.420   34.170    0.000   70.530   4.465    4.302    0.000
      H2S    0.892    0.068    0.569    0.000    2.539   0.182    0.180    0.002
      COS    0.048    0.004    0.038    0.000    0.117   0.010    0.010    0.001
      MEOH   0.000    0.000    0.000    0.000    1.320  95.037   95.411   99.923
      H2    33.440   44.310   13.870    0.000    0.000   0.000    0.000    0.000
      CO    17.030   20.580   22.020    0.000    0.980   0.214    0.098    0.030
      N2    26.190   33.040   26.490  100.000   23.580   0.093    0.000    0.044
      CH4    1.270    1.680    2.830    0.000    0.400   0.000    0.000    0.000
      C2H4   0.000    0.000    0.000    0.000    0.000   0.000    0.000    0.000
      C2H6   0.000    0.000    0.000    0.000    0.000   0.000    0.000    0.000

                                     *
                                      CALCULATED


                          MASS BALANCE (LB-MOLES/HR)
                          ---- -------


            IN                    OUT
            --                    ---
                                                               *        *
          SOUR     STRIP       SWEET    FLASH    ACID        TOTAL    TOTAL    % RECOVERY
          GAS      N2          GAS      GAS      GAS         IN       OUT

  CO2     0.476    0.000       0.007    0.019    0.517       0.476    0.544      114.2
  H2S     0.020    0.000       0.001    0.000    0.019       0.020    0.020       99.2
  COS     0.001    0.000       0.000    0.000    0.001       0.001    0.001       87.3
  MEOH    0.000    0.000       0.000    0.000    0.010       0.000    0.000        0.0
  H2      0.762    0.000       0.787    0.008    0.000       0.762    0.795      104.3
  CO      0.388    0.000       0.366    0.012    0.007       0.388    0.385       99.2
  N2      0.597    0.182       0.587    0.015    0.173       0.779    0.774       99.4
  CH4     0.029    0.000       0.030    0.002    0.003       0.029    0.034      118.7
  C2H4    0.000    0.000       0.000    0.000    0.000       0.000    0.000        0.0
  C2H6    0.000    0.000       0.000    0.000    0.000       0.000    0.000        0.0

  TOTAL   2.278    0.182       1.776    0.053    0.733       2.455    2.553      104.0
  (LB-MOLES/HR)

                               *
                                METHANOL-FREE BASIS

            TOTAL METHANOL LOSS=  0.010 LB-MOLES/HR =  0.046 GALLONS/HR
```

```
                                                RUN NUMBER A-M-36
                                                  INTEGRATED RUN
                                                 DATE    7/18/1980


                                     COLUMN TEMPERATURE PROFILES & MASS BALANCES
                                     ------ ----------- -------- - ---- --------


                   ABSORBER                          FLASH TANK                        STRIPPER

                  P=296.85 PSIG                      P= 96.85 PSIG                     P=  9.81 PSIG


                       ,---> SWEET                       ,---> FLASH                       ,---> ACID
                       :     GAS                         :     GAS                         :     GAS
                       :                                 :                                 :
                       :                                 :                                 :
                       :                                 :                                 :
                  10.63 SCFM                         0.33 SCFM                         4.39 SCFM
                       :                                 :                                 :
                       :                                 :                                 :
                       :                                 :                                 :
                  **********                             :                            **********
                  *        *                             :                            *        *
     MEOH FLOW    *        *                             :                            *        *
  --- 0.79 GPM -->*        *                             :              ,-- 0.79 GPM -*        *
      (-32.38  F) *        *                             :              :   (35.03 F) *        *
                  *        *                             :              :             *        *
                  *        *                        **********          :             *        *
                  * XXXXXX *                        *        *          :             * 17.94 F*
                  *        *                        *        *          :             *        *
                  * XXXXXX *                        *        *          :             * 16.83 F*
                  *        *                        *        *          :             *        *
                  *        *                        *        *          :             *        *
                  *        *                        *  8.99 F*          :             *        *
                  *        *                        *        *          :             *        *
                  * XXXXXX *                        *        *          :             * 15.66 F*
                  *        *          ,------------>*        *          :             *        *
                  * XXXXXX *          :             *        *          :             * 20.72 F*
                  *        *          :             *        *          :             *        *
                  *        *          :             *        *          :             *        *
                  *        *          :             *        *          :             *        *
                  *        *          :             *        *          :             *        *
                  *-30.20 F*          :             *        *          :             * 20.64 F*
                  *        *          :             *        *---------->             *        *
                  *-30.20 F*          :             *        *                        * 20.70 F*
                  *        *          :             **********                        *        *
                  *        *          :                                               *        *
     SOUR GAS     *        *          :                                               *        *
 -- 13.63 SCFM -->*        *          :                   STRIPPING N2-- 1.09 SCFM -->*        *
     ( 57.50 F)   *        *          :                                 (75.00 F)     *        *
                  * -1.72 F*          :                                               * 35.38 F*
                  *        *---------->                                               *        *
                  *        *                                                          *        *
                  *        *                                                          *        *
                  *        *                                                          *        *
                  **********                                                          **********
                                                                                           :
                                                                                           :
                                                                                           :
                                                                       <----TO ABSORBER-----
```

```
                                  RUN NUMBER A-M-36
                                    INTEGRATED RUN
                                   DATE    7/18/1980

                                COLUMN TEMPERATURE PROFILE
                                ------ ----------- -------


                                           .--------> SWEET GAS
                                           :          10.63 SCFM
                                           :
                                           :
                                           :
                                 *********************
                   MEOH FLOW     *                   *
                    0.790 GPM    *                   *
                   -32.38 F      *                   *
                 --------------->*                   *
                                 *                   *
                                 *===================*----  7.10 FT
                                 *                   *
                                 *                   *
                                 *                   *
                                 *                   *
                                 *                   *
                                 *    -30.20 F       *----  4.79 FT
ABSORBER PRESSURE =296.9 PSIG    *                   *
                                 *                   *
TOTAL PACKING HEIGHT= 7.10 FEET  *                   *
                                 *                   *
PACKING: 1/4" INTALOX SADDLES    *                   *
                                 *                   *
                                 *    -30.20 F       *----  2.46 FT
                                 *                   *
                                 *                   *
                                 *                   *
                                 *    -25.22 F       *----  1.21 FT
                                 *                   *
                                 *                   *
                                 *                   *
                                 *    -18.92 F       *----  0.79 FT
                                 *                   *
                                 *                   *
                                 *                   *
                                 *    -14.41 F       *----  0.31 FT
                                 *                   *
                                 *===================*----  0.00 FT
                                 *                   *
           --------------------->*                   *
              SOUR GAS INLET     *                   *
              13.63 SCFM         *                   *
              57.50 F            *     -1.72 F       *
                                 *                   *------------->
                                 *********************

                                     SOUR GAS (MOL %)          SWEET GAS (MOL %)
                                     ---- ---                  ----- ---

                 CO2                    20.9000                    0.4200
                 H2S                     0.8918                    0.0682
                 COS                     0.0476                    0.0038
                 MEOH                    0.0000                    0.0000
                 H2                     33.4400                   44.3100
                 CO                     17.0300                   20.5800
                 N2                     26.1900                   33.0400
                 CH4                     1.2700                    1.6800
                 C2H4                    0.0000                    0.0000
                 C2H6                    0.0000                    0.0000
```

```
                    *******************************************
                    *                                         *
                    * NCSU DEPARTMENT OF CHEMICAL ENGINEERING *
                    *                                         *
                    *      ACID   GAS   REMOVAL   SYSTEM      *
                    *                                         *
                    *******************************************

                               RUN NUMBER A-M-37
                                INTEGRATED RUN
                               DATE    7/25/1980

                          STREAM COMPOSITION (MOL %)
                          ------ -----------

                                                                     *          *          *
              SOUR      SWEET      FLASH      STRIP      ACID     ABSORB      FLASH      STRIP
              GAS       GAS        GAS        N2         GAS      EXIT        EXIT       EXIT

       CO2   25.050     0.640     47.820      0.000     72.900     5.406      4.983      0.000
       H2S    0.863     0.041      0.628      0.000      2.260     0.183      0.179      0.006
       COS    0.047     0.003      0.043      0.000      0.130     0.010      0.010      0.000
       MEOH   0.000     0.000      0.870      0.000      1.530    93.853     94.653     99.816
       H2    38.930    54.960     11.880      0.000      0.000     0.000      0.000      0.000
       CO    18.810    23.920     22.340      0.000      0.960     0.310      0.093      0.021
       N2    14.820    19.300     12.940    100.000     21.700     0.171      0.046      0.137
       CH4    1.150     1.160      3.140      0.000      0.230     0.067      0.037      0.021
       C2H4   0.000     0.000      0.000      0.000      0.000     0.000      0.000      0.000
       C2H6   0.000     0.000      0.000      0.000      0.000     0.000      0.000      0.000

                                        *
                                         CALCULATED


                          MASS BALANCE (LB-MOLES/HR)
                          ---- -------


             IN                          OUT
             --                          ---

                                                                         *          *
           SOUR     STRIP           SWEET     FLASH     ACID           TOTAL      TOTAL     % RECOVERY
           GAS      N2              GAS       GAS       GAS            IN         OUT

   CO2     0.579    0.000           0.011     0.049     0.583          0.579      0.642       110.9
   H2S     0.020    0.000           0.001     0.001     0.018          0.020      0.019        97.1
   COS     0.001    0.000           0.000     0.000     0.001          0.001      0.001       102.7
   MEOH    0.000    0.000           0.000     0.001     0.012          0.000      0.000         0.0
   H2      0.900    0.000           0.925     0.012     0.000          0.900      0.937       104.1
   CO      0.435    0.000           0.402     0.023     0.008          0.435      0.433        99.5
   N2      0.343    0.182           0.325     0.013     0.173          0.525      0.511        97.4
   CH4     0.027    0.000           0.020     0.003     0.002          0.027      0.025        92.4
   C2H4    0.000    0.000           0.000     0.000     0.000          0.000      0.000         0.0
   C2H6    0.000    0.000           0.000     0.000     0.000          0.000      0.000         0.0

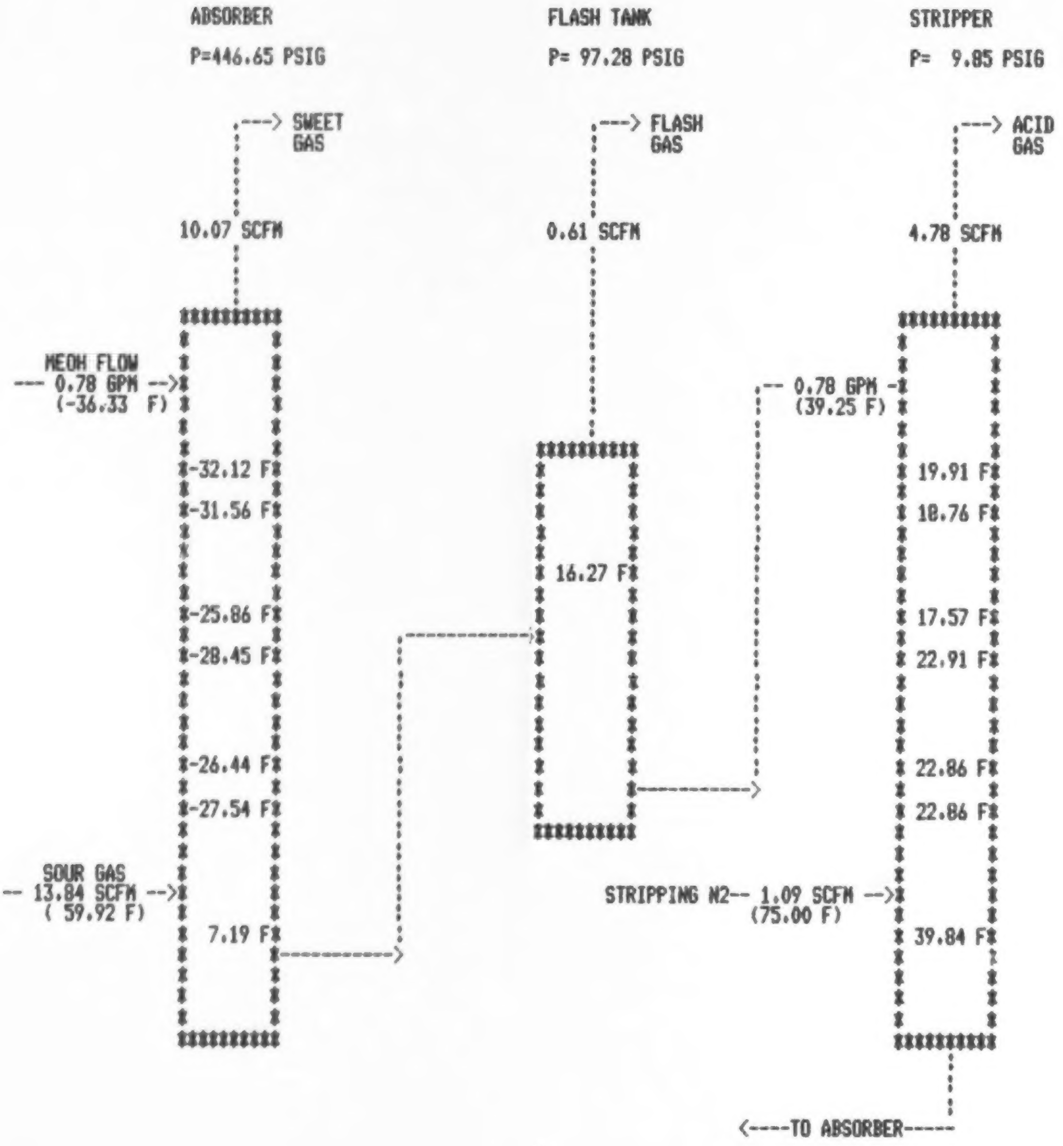
   TOTAL   2.313    0.182           1.683     0.102     0.799          2.487      2.569       103.3
   (LB-MOLES/HR)

                                   *
                                    METHANOL-FREE BASIS

                 TOTAL METHANOL LOSS=  0.013 LB-MOLES/HR =  0.062 GALLONS/HR
```

RUN NUMBER A-M-37
INTEGRATED RUN
DATE 7/25/1980

COLUMN TEMPERATURE PROFILES & MASS BALANCES


ABSORBER
P=446.65 PSIG
SWEET GAS
10.07 SCFM
MEOH FLOW
0.78 GPM
(-36.33 F)
-32.12 F
-31.56 F
-25.86 F
-28.45 F
-26.44 F
-27.54 F
SOUR GAS
13.84 SCFM
(59.92 F)
7.19 F
FLASH TANK
P= 97.28 PSIG
FLASH GAS
0.61 SCFM
16.27 F
STRIPPER
P= 9.85 PSIG
ACID GAS
4.78 SCFM
0.78 GPM
(39.25 F)
19.91 F
18.76 F
17.57 F
22.91 F
22.86 F
22.86 F
STRIPPING N2
1.09 SCFM
(75.00 F)
39.84 F
TO ABSORBER

```
                          RUN NUMBER A-M-37
                           INTEGRATED RUN
                          DATE    7/25/1980

                      COLUMN TEMPERATURE PROFILE
                      ------ ----------- -------

                            ,---------> SWEET GAS
                            :            10.07 SCFM
                            :
                            :
                            :
                            :
                   *********************
        MEOH FLOW  *                   *
         0.784 GPM *                   *
        -36.33 F   *                   *
     -------------->*                  *
                   *                   *
                   *===================*----    7.10 FT
                   *                   *
                   *                   *
                   *                   *
                   *                   *
                   *     -26.64 F      *----    4.79 FT
ABSORBER PRESSURE =446.6 PSIG          *
                   *                   *
TOTAL PACKING HEIGHT= 7.10 FEET        *
                   *                   *
PACKING: 1/4" INTALOX SADDLES          *
                   *                   *
                   *     -27.54 F      *----    2.46 FT
                   *                   *
                   *                   *
                   *     -22.20 F      *----    1.21 FT
                   *                   *
                   *                   *
                   *     -16.03 F      *----    0.79 FT
                   *                   *
                   *                   *
                   *     -10.07 F      *----    0.31 FT
                   *===================*----    0.00 FT
                   *                   *
   ---------------->*                  *
      SOUR GAS INLET                   *
      13.84 SCFM   *                   *
      59.92 F      *       7.19 F      *
                   *                   *--------------->
                   *********************

                         SOUR GAS (MOL %)          SWEET GAS (MOL %)
                         ---- ---                  ----- ---

          CO2               25.0500                    0.6400
          H2S                0.8631                    0.0405
          COS                0.0475                    0.0027
          MEOH               0.0000                    0.0000
          H2                38.9300                   54.9600
          CO                18.8100                   23.9200
          N2                14.8200                   19.3000
          CH4                1.1500                    1.1600
          C2H4               0.0000                    0.0000
          C2H6               0.0000                    0.0000
```